

**Executive and Technical
Summary Report on
Propane Bus Demonstration –
Ottawa-Carleton Regional Transit Commission**



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Executive and Technical Summary Report on Propane Bus Demonstration – Ottawa-Carleton Regional Transit Commission

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Prepared for:

Ottawa-Carleton Regional Transit Commission
Energy, Mines and Resources Canada
Ministry of Energy, Ontario
Ministry of Transportation, Ontario

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EXECUTIVE AND TECHNICAL SUMMARY

1. Background

The Ottawa-Carleton Regional Transit Commission (OC Transpo) has completed 37 months of operation of a fleet of propane-fuelled buses and is now able to report its findings on the cost, problems and benefits of the propane buses and to compare them with conventional diesel buses operated by the Commission.

The operation of the propane buses was part of a three-phase demonstration program initiated in 1984, budgeted at a total of \$1,656,000 and funded jointly by OC Transpo, Ministry of Energy Ontario and Energy, Mines and Resources Canada. The program was managed by a multi-agency Steering Committee, whose Chairman was the General Manager of OC Transpo with membership from EMR Canada, the Ontario Ministries of Energy and Transportation, and the OC Transpo Project Manager. The project was managed on a daily basis by OC Transpo with technical assistance from the Ministry of Transportation, Ontario. Valuable technical support was also given by the propane engine supplier, Dereco Ltd. of Switzerland (a division of Fiat) and the propane supplier, Superior Propane Ltd.

2. Objectives and Rationale

The principal objective was "to carry out a demonstration of the technology and economics of propane utilization as a transportation fuel for transit fleet vehicles and to assess the reliability, safety, operability and public response to propane-fuelled buses operating in revenue service".

The objective was set and the demonstration program undertaken in response to concerns at OC Transpo and other properties with the then prevailing trend in price and supply of diesel fuel. The government

agencies involved in the program recognized these issues and the importance of substituting diesel fuel (derived from imported crude oil) by alternative fuels such as propane, which in Canada is in surplus supply and low in cost. Importance was also attached to improvements in the urban environment by use of smoke-free propane buses.

3. Components of the Demonstration

The status of propane engine technology, cost and timing led to the decision to retrofit existing 40 foot GM transit buses with propane engines and to the selection of monofuel spark-ignition engines produced by modifying commercially-available 4-stroke diesel engines. No N. American engine manufacturer responded to the propane engine requirement and the engines were purchased from a division of Fiat (Dereco).

The monocoque construction of the GM buses permitted the addition of a large propane storage tank. A new assembly was designed and supplied by Westeel Corporation of Winnipeg. This robust assembly carries 640 litres of propane (80% filling of 800 litre capacity tank) - sufficient for a bus range in excess of 600km.

Ten buses were converted to propane by OC Transpo maintenance staff and one reconverted to diesel before 31 December 1987, thereby demonstrating the ease of the reversion process. After that date three buses were reconverted to diesel and the propane engines reserved for dismantling and a detailed examination. The remaining propane buses were reconverted to diesel as engine failure occurred and the project terminated on 31 March 1988.

During the 37-month period to 31 December 1987 the propane buses were operated over 1.4 million kilometers, providing service to about 2.5 million passengers. A fleet of ten diesel buses was also monitored throughout 1987. The diesel fleet operated over 587,000 kilometers.

The propane supplier was selected by competitive bid and provided the two tank, 12,000 litre total capacity propane storage facility and dispenser located at the St. Laurent Boulevard garage of OC Transpo. The propane buses have been refuelled with 1.5 million litres of propane through this facility without incident. The propane bus refuelling time of 4 minutes is not significantly different from that for diesel buses, despite the increased volume of propane dispensed at each fill (240 litres/fill on average in 1987).

The garage was equipped with portable propane detectors and new fire extinguishers, but large investments in new ventilation equipment and fixed propane detection equipment were not made. It was considered more appropriate to provide thorough staff training, supervision and signage. Propane conversion and repair operations were conducted in areas within the garage where propane spills could be minimized.

It was decided that extensive conversion of the garage to permit the overnight inside parking of propane buses would be deferred and certain inefficiencies in propane bus operations in the winter months can be traced to outdoor parking and cold engines.

Twenty-nine members of the OC Transpo maintenance staff qualified as propane fitters through courses at Algonquin College and provincial certification. Eighteen maintenance staff are also certified by the Province for inspection and approval of propane vehicle conversions.

The bus drivers were also given instruction on propane safety, but the similarity of the propane bus to the conventional diesel bus obviated the need for driver re-orientation.

Comparative data on the propane and diesel engines was provided by tests conducted at the Ontario Research Foundation, under the management and sponsorship of the Ministry of Transportation, Ontario and Energy, Mines and Resources Canada.

A microcomputer-based system was installed to facilitate the collection, analysis and reporting of detail on the manpower, materials and costs involved in operating the propane fleet. In 1987 data collection and reporting was extended to include detail on 10 diesel-powered buses of the same age and type as those in the propane fleet.

4. Outcome of the Demonstration

4.1 Realization of Objectives

The principal objectives of the demonstration were achieved. Sufficient information was gathered to permit an evaluation of the costs and performance of the propane fleet under revenue service conditions. A valid comparison was therefore made with the costs and performance of a similar fleet of diesel-powered buses operated under the same revenue service conditions. OC Transpo staff are trained in the conversion, operation and maintenance of propane buses, which were an integral part of bus operations at OC Transpo.

4.2 Bus Performance

Exhibit ETS-1 summarizes a comparative assessment of the propane and diesel buses operated in the demonstration. The overall assessment is that the propane buses have provided a satisfactory level of performance compared to the diesel buses under the conditions of the demonstration and current requirements. The present propane engines are essentially prototypes and utilize propane carburetion equipment and technologies of the 1982-3 era which, while suitable for conversion of gasoline-powered automobiles and small trucks, are not rugged enough for the extreme requirements of transit bus operations. The deficiencies of the in-vehicle propane system and potential remedies have been defined and changes made where feasible.

Exhibit ETS.1
Comparison of Propane and Diesel Buses
Based on 1987 Demonstration Data

<u>CATEGORY</u>	<u>RATING*</u>	<u>COMMENTS ON PROPANE BUS</u>
1 Rider Acceptance	C	Riders indifferent. May be possible to promote low pollution, low noise advantage
2 Driver Acceptance	C	Call reports indicate problems with steering stiffness, odour, startability, power
3 Bus Utilization	C	Diesel buses had old engines, propane new ones
4 Bus Availability	C	Propane buses require extra effort to start in winter because of outdoor storage. Once started availability similar to diesel
5 Refuelling	C	Safe, fast as diesel
6 Safety	W	4 small fires; problem solved. Concerns only over indoor parking remain
7 Exhaust Emissions	B	Low smoke advantage but NOx not yet controlled: technology is available
8 Engine Component Durability	W	Unsatisfactory durability of prototype equipment
9 Operating Costs	B	Propane fuel cost savings predominate
10 Maintenance Costs	W	Improvements defined but not implemented
11 Total Operating Costs	C	Sum of Operating and Maintenance Costs
12 Capital Cost	W	\$20,000 premium for conversions: may not apply to new buses
<u>OVERALL ASSESSMENT</u>		
13 Current Bus	W	Adequate: technology upgrades need implementation
14 Future Bus	C or B	New design fuel and pollution controls

* Rating relative to diesel: C = comparable to diesel bus
 B = better than diesel bus
 W = worse than diesel bus

In this way the utilization rate of propane buses has been improved over the demonstration period to the extent that in 1987 the propane fleet had a daily utilization rate somewhat higher than the diesel buses measured in the demonstration and variations of bus availability within the propane fleet were not significantly different from those in the diesel fleet.

The range of the propane buses with the current 640 litre propane storage tank was demonstrated to be suitable for all revenue service requirements. Propane buses were therefore intermingled with the diesel fleet.

Public acceptance of propane buses was not less than that of the diesel buses - the public was unaware or indifferent to the fuel used.

Driver response to the buses was encouraging. The low noise, low vibration and excellent acceleration from stop were noted, but enthusiastic acceptance was tempered by the stiff steering of the (heavier than diesel) propane bus and by the higher level of road calls experienced. Stiff steering would not be a factor in current buses which have power-assisted steering, or in buses retrofitted with power steering.

Direct operating costs of the propane buses in 1987 were somewhat lower than those of diesel buses, due to the lower cost of propane. The magnitude of the cost advantage was reduced by high propane consumption in winter due to outdoor parking and extended warm-up of the buses and by unexpected decreases in the cost of-diesel fuel.

Maintenance costs of the propane fleet were substantially higher than those of the diesel buses, due in part to high wear experienced in the carburetion equipment and in part to high demand load upon the electrical equipment, due to outdoor parking of buses in winter.

The capital cost of the conversion cannot be recovered within the present cost structure. The residual life of buses already used for 4-5 years reduces the time period in which operating cost savings can be made. The accumulated savings may be insufficient to pay out the \$20-30,000 conversion investment.

The safety record of the propane buses was very good. 4 minor fires caused by combustion of leaking crankcase oil (not related to propane in the opinion of OC Transpo staff) were detected at an early stage and caused no injuries and no significant damage to the engines or to other property. The source of the oil leaks was identified and the problem did not recur after the correction was made.

The outstanding feature of the propane bus is the almost total absence of smoke in the exhaust. The cost will be high of modifying diesel engines and diesel fuel to meet the stringent bus particulate emission standards which will be in place after 1990. The modification required to the propane engine to meet the anticipated post-1990 standards will be much less expensive and the technology of 3-way catalyst exhaust treatment has already been demonstrated in propane engines and is in use in all automobiles recently manufactured in N. America. The catalyst system for propane engines is needed to reduce the NOx level to the 1990+ standard.

A summary of the key data from the demonstration is given in Exhibit ETS.2a-d.

5. Conclusions

- i. The demonstration has shown that propane buses can be utilized in urban transit applications.
- ii. Propane buses had total costs somewhat higher than those on diesel fuel at the prevailing depressed crude oil and diesel fuel prices.

- iii. The safety record of the propane buses was excellent and equivalent to that of the diesel bus fleet.
- iv. The demonstration defined engineering and equipment changes which, if implemented, could provide a level of service and costs fully competitive with those of the current diesel buses.
- v. Legislation to limit the particulate emissions of buses is expected to increase the cost and complexity of diesel buses produced after 1990 to the point where propane buses may well provide lower cost and higher availability.
- vi. The competitiveness of the propane bus will be increased if design features are included in its manufacture which will increase component durability and reduce the frequency and cost of maintenance. Many of these design features have already been demonstrated in buses recently delivered to Vienna Transit.

6. Recommendations

- i. Propane should be considered as a fuel for transit buses by properties where outdoor parking and bus operation are not affected by extremely cold weather and blowing snow.
- ii. Government agencies should continue to monitor developments in propane technology, particularly for transit operations.
- iii. The improvements defined in the present demonstration should be verified in a further propane bus demonstration.
- iv. Future demonstrations of propane buses should utilize a management structure and data-gathering and analysis process similar to those developed during this demonstration.

Exhibit ETS.2a

Summary of Findings

PROPANE

OC TRANSPRO PROPANE FLEET COSTS 1987

FLEET to	MAINTENANCE \$	OPERATIONS \$	TOTAL \$/1000	FUEL ECON \$/1000
JANUARY 40730	10697	17909	28.66	40.41
FEBRUARY 40224	16489	10573	26.29	67.20
MARCH 45987	4758	10642	23.14	33.49
APRIL 43599	9938	10408	20.86	46.85
MAY 30624	2003	8183	21.19	20.44
JUNE 40750	4101	9227	22.64	32.90
JULY 36281	1336	6795	18.73	22.41
AUGUST 31359	3550	6556	20.91	32.23
SEPTEMBER 39600	4917	8072	20.34	32.73
OCTOBER 47604	5834	16314	34.21	46.45
NOVEMBER 40443	3932	11274	23.27	31.39
DECEMBER 41601	9177	11245	26.90	49.00
TOTAL 1987 503650	77611	122358	24.32	39.75
"WINTER" (NOV-APR)	54990	67211	25.02	45.40
"SUMMER" (MAY-OCT)	22621	55147	23.53	33.10

OC TRANSPRO PROPANE USE DATA 1987

FUEL ADDED litres	FILLS #	AVG FILL litres	FUEL DEL INVENTORY TO SITE litres	CHANGE litres
JANUARY 61967	216	287	60551	-1416
FEBRUARY 49349	169	292	50950	1601
MARCH 53225	192	278	54550	1225
APRIL 65571	184	248	41900	-3671
MAY 30896	179	206	38916	2020
JUNE 30017	182	213	35870	-2947
JULY 32946	173	190	38661	5715
AUGUST 31990	165	194	29650	-2340
SEPTEMBER 35440	187	212	33700	-5940
OCTOBER 40312	194	249	57793	9401
NOVEMBER 55876	212	228	48301	-2575
DECEMBER 56503	192	337	64697	8194
TOTAL 1987 551192	2245	246	555539	4347
"WINTER" (NOV-APR)	32591	1165	320949	-1642
"SUMMER" (MAY-OCT)	22601	1000	234590	5909

OC TRANSPRO FLEET COST/US-OPERATING DAY 1987

KM/US /FILL	OP COST /US DAY	MAINT COST /US DAY	TOTAL COST /US DAY
JANUARY 226	40.13	49.52	109.66
FEBRUARY 238	42.56	97.57	160.13
MARCH 240	55.43	24.78	80.21
APRIL 237	57.00	54.01	111.01
MAY 216	45.72	15.66	61.37
JUNE 224	50.70	22.97	73.67
JULY 210	39.28	7.72	47.00
AUGUST 190	39.73	21.52	61.25
SEPTEMBER 212	43.17	26.29	69.46
OCTOBER 246	84.09	30.07	114.16
NOVEMBER 229	53.18	18.55	71.73
DECEMBER 217	58.57	47.00	106.56
TOTAL 1987 224	54.50	34.57	89.07
"WINTER" (NOV-APR)	231	57.49	104.89
"SUMMER" (MAY-OCT)	217	51.06	72.01

Exhibit ETS.2b

Summary of Findings

D I E S E L

OC TRANSPO DIESEL FLEET COSTS 1987

FLEET No	MAINTENANCE \$	OPERATIONS \$	TOTAL \$/100km	FUEL ECON \$/100km
JANUARY 63856	6027	13089	21.00	30.44
FEBRUARY 62842	602	14761	23.46	24.54
MARCH 55540	16423	13436	23.76	53.16
APRIL 47002	6105	11316	24.83	37.00
MAY 43620	845	11175	25.73	27.60
JUNE 46502	2126	13522	29.66	34.19
JULY 42856	2739	8969	20.00	27.27
AUGUST 43706	3091	12818	29.33	30.23
SEPTEMBER 41455	3249	9910	23.92	31.76
OCTOBER 51256	4222	11693	27.81	31.05
NOVEMBER 52449	371	12786	24.37	25.00
DECEMBER 34724	2229	8012	23.87	29.49
TOTAL 1987 507140	49109	142173	24.21	32.50

"WINTER" (NOV-APR)	317493	37037	10.89	33.60
"SUMMER" (MAY-OCT)	269647	17072	6.33	31.73

OC TRANSPO DIESEL USE DATA 1987

ADDED Litres	FILLS #	AVG FILL Litres	FUEL DEL INVENTORY TO SIZE Litres
JANUARY 32953	226	146	N/A
FEBRUARY 36394	235	155	N/A
MARCH 32941	249	132	N/A
APRIL 26060	209	135	N/A
MAY 22955	193	124	N/A
JUNE 24410	168	145	N/A
JULY 22157	121	183	N/A
AUGUST 21914	120	171	N/A
SEPTEMBER 21075	149	141	N/A
OCTOBER 25532	161	159	N/A
NOVEMBER 27527	154	179	N/A
DECEMBER 18722	145	129	N/A
TOTAL 1987 313700	2130	147	N/A

"WINTER" (NOV-APR)	174005	1210	143
"SUMMER" (MAY-OCT)	139103	930	151

OC TRANSPO DIESEL COST/OPS-OPERATING DAY 1987

EM/OPS /FILL	OP COST /OPS DAY	MAINT COST /OPS DAY	TOTAL COST /OPS DAY
JANUARY 203	59.33	26.67	86.00
FEBRUARY 267	62.73	2.90	65.63
MARCH 227	53.96	66.76	120.72
APRIL 225	54.14	29.21	83.35
MAY 225	57.90	4.30	62.20
JUNE 279	82.87	12.65	95.52
JULY 354	73.96	22.64	96.60
AUGUST 341	100.14	30.40	130.54
SEPTEMBER 278	66.56	21.81	88.37
OCTOBER 310	72.63	26.22	98.85
NOVEMBER 341	83.01	2.41	85.42
DECEMBER 239	55.26	15.37	70.63
TOTAL 1987 275	66.50	22.97	89.47

"WINTER" (NOV-APR)	261	60.51	26.30
"SUMMER" (MAY-OCT)	293	74.43	18.56

Exhibit ETS.2c

Summary of Findings

PROPANE

OC TRANSPO PROPANE FLEET COSTS 1966

FLEET No	MAINTENANCE \$	OPERATIONS \$	TOTAL \$	FUEL ECON 1/100m
JANUARY	38933	12734	51,67	138.74
FEBRUARY	43485	13765	57,25	128.24
MARCH	27883	9938	37,82	135.79
APRIL	35783	7882	43,66	112.14
MAY	25373	5157	30,53	102.21
JUNE	36541	8451	44,99	91.83
JULY	55361	11454	66,81	87.54
AUGUST	44153	7621	51,77	86.17
SEPTEMBER	45811	10896	56,70	97.27
OCTOBER	58147	12257	70,40	104.44
NOVEMBER	44749	12979	57,72	119.86
DECEMBER	47875	18529	66,40	110.66
TOTAL 1966	495214	122855	618,06	100.13
"WINTER" (NOV-APR)	237828	67819	305,64	123.13
"SUMMER" (MAY-OCT)	257386	55036	312,42	96.27

OC TRANSPO PROPANE USE DATA 1966

FUEL ADDED Litres	PILLS #	AVG PILL Litres	FUEL DEL INVENTORY TO SITE Litres
JANUARY	54014	180	57125
FEBRUARY	55764	172	57836
MARCH	36775	124	33651
APRIL	40037	149	45458
MAY	25934	166	20793
JUNE	37262	155	31878
JULY	48464	210	49878
AUGUST	38847	178	35551
SEPTEMBER	44559	191	50102
OCTOBER	52372	209	47188
NOVEMBER	53276	195	54383
DECEMBER	52977	191	54585
TOTAL 1966	535481	2032	538420
"WINTER" (NOV-APR)	292843	1811	303838
"SUMMER" (MAY-OCT)	242638	1841	234582

OC TRANSPO FLEET COST/INS-OPERATING DAY 1966

	KN/INS /PILL	OP COST /INS DAY	MAINT COST /INS DAY	TOTAL COST /INS DAY
JANUARY	216	78.74	40.26	119.01
FEBRUARY	253	80.03	58.84	138.87
MARCH	218	80.00	61.86	141.86
APRIL	240	52.90	39.91	92.81
MAY	239	48.65	40.42	89.07
JUNE	236	54.52	41.44	95.96
JULY	284	54.54	31.90	86.45
AUGUST	260	44.83	13.62	58.45
SEPTEMBER	240	52.86	30.72	83.58
OCTOBER	240	58.65	14.82	73.47
NOVEMBER	239	66.56	32.24	98.80
DECEMBER	251	55.13	19.62	74.75
TOTAL 1966	241	59.87	34.35	94.22
"WINTER" (NOV-APR)	235	67.00	40.47	107.47
"SUMMER" (MAY-OCT)	247	52.87	28.40	81.27

Exhibit ETS.2d

Summary of Findings

PROPANE

OC TRANSPO PROPANE FLEET COSTS 1965

FLEET No	MAINTENANCE \$ /100ha	OPERATIONS \$ /100ha	TOTAL \$ /100ha
JANUARY 6118			128.99
FEBRUARY 21300			98.19
MARCH 25855			85.78
APRIL 18299			116.98
MAY 24004			109.53
JUNE 24878			75.72
JULY 31796			78.82
AUGUST 47149			88.78
SEPTEMBER 47089	3416	11589	31.49
OCTOBER 56583	4495	11789	32.24
NOVEMBER 41895	4146	10489	36.10
DECEMBER 33837	5543	12756	54.08
TOTAL 1965 374795	17590	46743	97.11

"WINTER"
(NOV-APR)

109.84

"SUMMER"
(MAY-OCT)

88.56

OC TRANSPO PROPANE USE DATA 1965

PROPANE ADDED litres	FILLS #	AVG FILL litres	FUEL DEL INVENTORY TO SITE litres
JANUARY 7482			
FEBRUARY 19283			
MARCH 22178			
APRIL 21407			
MAY 27167			
JUNE 28147			
JULY 22263			
AUGUST 38886			
SEPTEMBER 43661	150	276	47615
OCTOBER 51449	187	275	51227
NOVEMBER 46772	140	292	49255
DECEMBER 43963	149	295	44087
TOTAL 1965 363978			

"WINTER"
(NOV-APR)

161885

"SUMMER"
(MAY-OCT)

202573

OC TRANSPO FLEET COST/INS-OPERATING MAY 1965

MONTH	EN/INS /FILL	OP COST /INS DAY	MAINT COST /INS DAY	TOTAL COST /INS DAY
JANUARY				
FEBRUARY				
MARCH				
APRIL				
MAY				
JUNE				
JULY				
AUGUST				
SEPTEMBER	298	72.44	21.41	94.45
OCTOBER	278	63.04	24.04	87.08
NOVEMBER	257	64.41	25.91	92.72
DECEMBER	227	65.41	37.20	122.81



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APPENDIX UNDER SEPARATE COVER

1. Contracts
2. Fuels for Buses
3. Data Collection and Analysis System
4. Technical Specifications
5. Details of Bus Performance and Engine Tests
6. Safety Manual
7. List of Project Reports and Publications
8. Vehicle Road Calls: Problems and Solutions



EXECUTIVE SUMMARY

1. Background

The Ottawa-Carleton Regional Transit Commission (OC Transpo) has completed a 37 month demonstration of the use of propane-fuelled buses in revenue service. Data on the safety, operation, maintenance, and economics of the 10 buses in the propane fleet have been assembled and compared with those from a 12 month monitoring of a fleet of 10 diesel-engined buses of the same age and type. Rider and driver response to the propane buses was also assessed.

The 10 propane buses were operated over 1.4 million kilometers of revenue service providing transportation to some 2.5 million passengers. The \$1.656 million cost of the demonstration was shared by the Commission, Energy, Mines and Resources Canada and the Ontario Ministry of Energy. Representatives of these agencies and of the Ministry of Transportation Ontario provided program management through a Steering Committee. Project management was provided by OC Transpo with assistance from the Ministry of Transportation Ontario.

2. Findings and Conclusions

The overall assessment is that propane buses provided a satisfactory level of performance compared to the diesel buses under the conditions of the demonstration and current requirements.

Public acceptance of the propane buses is not less than that of the diesel buses. The public is unaware or indifferent to the fuel used.

The safety record of the buses and the refuelling facility was very good: there were no major incidents.

The propane buses provided a level of daily availability comparable to that of the average diesel bus, but more staff effort was required to provide the required availability. The principal problem affecting this effort was the difficulty in starting the buses in winter, attributed in part to the outdoor storage of the propane buses for safety reasons. Diesel buses do not experience this problem, since they are stored inside the garage at OC Transpo.

The in-service performance of the propane buses was excellent. They matched the acceleration, speed and route timing of the diesel buses and their range was demonstrated to be suitable for all revenue service requirements within the OC Transpo system, including urban and long-distance suburban routes.

Driver response was excellent. The low noise, low vibration, and excellent acceleration of these buses, and absence of smoke in the exhaust emissions was noted by the drivers, but stiff steering was also noted. This would not be a factor if current GM buses were converted since they have power-assisted steering. The older model buses could be retrofitted with power steering.

The direct operating costs of the propane buses were only marginally lower than those of diesel buses. The low cost of propane relative to diesel was substantially offset by the higher volumes of propane used and particularly by the propane consumed during extended warm-up of the buses on winter mornings.

The maintenance costs of the propane fleet were substantially higher than for the monitored diesel fleet. This was due in part to high wear and unsatisfactory durability experienced in the carburetion equipment and in part to the high demand load on the electrical equipment associated with outdoor winter parking.

The total operating costs (direct operating and maintenance costs)

of the 1979 vintage buses retrofitted for the propane demonstration was somewhat higher than for the equivalent diesel buses.

The demonstration defined the engineering and equipment changes, which, if implemented, could provide a level of service and costs fully competitive with those of the current diesel bus. A number of these design features have already been demonstrated in buses recently delivered to Vienna Transit.

Legislation to limit the emissions from buses is expected to be in force in Canada by 1991. It will increase the cost and complexity of buses and particularly of diesel-fuelled buses which will require particulate traps. In this era, the propane bus equipped with a 3-way catalyst system similar to those developed for gasoline and methanol engines, is expected to have significantly lower operating and maintenance costs than the trapped diesel buses.

3. Recommendations

- i. Propane may be considered as a fuel for transit buses by properties where outdoor parking and bus operation are not affected by extremely cold weather.
- ii. The improvements defined in the present demonstration should be verified in a further propane bus demonstration.
- iii. Future demonstrations of propane buses should utilize a management structure and data-gathering and analysis process similar to those developed during this demonstration.

1. INTRODUCTION

1.1 Background and Rationale for the Demonstration

In 1982 the Ottawa-Carleton Regional Transit Commission (OC Transpo) investigated trends in the cost, supply and quality of diesel fuel and concluded that the Commission should investigate the use of alternative fuels in transit buses. Propane was selected in view of its ready availability in Canada and its low price relative to diesel fuel. Some experience had already been gained at OC Transpo in the use of propane in the non-revenue fleet of automobiles and small trucks. A great deal of information was available on the use of propane, since the Chicago Transit Authority and several other American transit properties had operated bus fleets on propane (or, as then termed, LPG, liquefied petroleum gas) in the 1950's and 60's with modified heavy-duty gasoline engines as an alternative to the then developing substitution of gasoline by diesel fuel. The experience with propane engines derived from gasoline engines could not be directly used to direct the OC Transpo demonstration.

The only bus fleets operating with heavy duty engines fuelled by alternative fuels in 1982 were in Vienna and Amsterdam and the technology used in those buses was not considered suitable for use in Canada in the mid-1980's. The technology for other alternative fuels, such as compressed natural gas and methanol, was judged (in 1982) to be less developed than that for propane. Accordingly, OC Transpo decided to undertake a demonstration program with propane buses operated in revenue service for a period of time sufficient to permit generation and analysis of data needed for future decisions on the adoption of propane as a transit bus fuel at OC Transpo and other bus properties in Canada.

The rationale for the propane demonstration included:

1. A need to generate information on propane bus system operations

and costs under Canadian conditions and to compare these with current costs in the diesel fleet.

- ii. The opportunity to collect revenue service data on propane buses operated in the Canadian environment.
- iii. A route to lower fuel costs and containment of operating costs at OC Transpo.
- iv. Diversification of fuel sources to offset possible future diesel fuel shortages.
- v. Utilization of the surplus supply of Canadian fuel in place of crude oil-dependent diesel fuel in a future when Canada must increase its dependence on imported crude oil.
- vi. Improvement in the quality of the environment through use of propane, which essentially eliminates particulate emissions in the bus exhaust.

The unknown factors at the outset of the demonstration included:

- i. No N. American-manufactured propane engines were available.
- ii. European engine technology was not directly transferrable to OC Transpo operations.
- iii. While propane fuel cost could be forecast, no information was available on maintenance and other costs.
- iv. Rider and driver response to the new vehicles was not known.
- v. No experience existed at OC Transpo on the safety of operations involving propane buses. Experience was necessary on refuelling,

bus maintenance and storage and on in-service operations.

The propane bus demonstration was implemented in 3 phases:

Phase 1: Bus Acquisition and Proof of Operability
15 November 1983 to 31 March 1985

Phase 2: In-Revenue Service
1 April 1985 to 31 March 1987

Phase 3: Extended Service and Detailed Analysis
1 April 1987 to 31 March 1988.

This report provides data to 31 December 1987.

1.2 Objectives

Exhibit 1.1 shows demonstration goals and status of each phase.

1.2.1 Phase 1

The principal objective of Phase 1 was defined as follows:

"To carry out a demonstration of the technology and economics of propane utilization as a transportation fuel for transit fleet vehicles, and to assess the reliability, safety, operability, and public response to propane-fuelled buses in urban transit service".

The scope of the demonstration program of Phase 1 was to establish the feasibility of conducting a large-scale demonstration of propane buses operating in revenue service.

Exhibit 1.1
Demonstration Goals and Status

GOALS

STATUS AT 31.12.87

PHASE 1

Select propane engine manufacturer
Adapt engine for retrofit into standard "New Look" GM bus
Conduct GO/NO-GO test of prototype retrofitted bus
In-service operations to determine bus performance/driver acceptance
Purchase 15 propane and one 4-stroke diesel engine
Convert 15 buses to propane
Design and install propane fuelling, storage facilities

Iveco/Dereco selected
Complete
Successful test
More data from Phase 2
Complete
7 converted to propane
Complete

PHASE 2

Complete conversions to 15 propane buses, one 4-stroke diesel
Develop improved refuelling practices and equipment
Install and demonstrate new facilities in St. Laurent garage
to provide safe propane bus storage and repair
Operate propane fleet in revenue service to 31 March 1987
Develop and operate data collection/analysis system
Communicate demonstration findings to transportation communities

10 converted to propane
Complete
Limited installation
Complete
Complete
Partially complete

PHASE 3

Collect comparative data on propane/diesel fleet costs and operations
Operate one propane bus with a new governor and fuel system
and one with reduced compression ratio
Decide future of propane engines and other demonstration equipment

In progress
In progress
In progress

As reported in the Phase 1 final report, the goals set were not met in their entirety: only 7 buses were converted in the project period and the in-revenue service experience with propane buses was therefore limited. Furthermore, it was foreseen that valuable new information could be obtained from an extension of the demonstration.

A two-year Phase 2 of the demonstration was therefore instituted beginning 1 April 1985.

1.2.2 Phase 2

The scope of Phase 2 was to build upon the feasibility and results established in Phase 1.

The goals of the Phase 2 demonstration were met with two exceptions. It was decided that:

- (a) due to a shortage of buses at OC Transpo, conversion and operation of 10 buses on propane would provide sufficient information and
- (b) the expense of equipping the St. Laurent garage with propane detection and new ventilation systems would not be undertaken.

1.2.3 Phase 3

It was agreed that the demonstration would be extended for a further year.

1.3 Contract and Requirements Summary

The contract documents and requirements are given in Appendix 1. The principal requirements defined in the contract for each phase are summarized in Exhibit 1.2.

Exhibit 1.2
Contract Tasks and Status

TASKS

STATUS AT 31.12.87

PHASE 1

Purchase propane engines	Complete
Modify GM buses at OCT	Complete
Install fixed facilities	Sufficient installed for demonstration
Purchase spare parts and tools	Complete
Execute inspection program for acceptability of propane buses	Complete
Obtain municipal authority required to operate propane-powered buses	Complete
Operate/maintain propane buses to normal OCT standards	Complete
Operate propane buses to achieve objectives of demonstration	Complete
Identify information for analysis of purpose of demonstration	Complete
Maintain detailed operation/maintenance records	Complete
Steering Committee to advise project team, monitor/report progress	Complete, but more detail sought
	Established

PHASE 2

Complete propane bus conversions and one diesel engine	10 propane
Evaluate converted vehicles over 24 month period	Complete
Inspect buses after conversion, 12 months in service, at project completion	Complete
Develop regular inspection/test program on bulk fuel storage and vehicle refuelling facility	Complete
Maintain records on components, conversion problems, engine settings, dynamometer tests on the engine, safety tests, monitoring, analysis	Complete
Install safety equipment in garage	Partial completion
Monitor fuel consumption	Complete
Monitor developments in bus exhaust and noise emission legislation	In progress
Develop computer-based data acquisition, analysis, reporting system	Complete
Prepare final reports and other documentation	Complete

PHASE 3

Operate not less than 5 propane buses for a period of one year	In process, 9 buses operating
Issue final report on Phase 2, revised after completion of Phase 3	Complete: this report
Assist in preparation of publicity material, information transfer on total demonstration project - Phases 1, 2 and 3	In progress

The contract for Phase 1 also provided schedules detailing:

- . terms of reference
- . definition of the tasks
- . requirements of the GO/NO GO propane bus acceptance tests
- . technical specifications for engine and in-vehicle fuel controls.

2. ORGANIZATION OF THE DEMONSTRATION

2.1 Activities Involved

Exhibit 2.1 summarizes the principal activities involved in the propane bus demonstration.

2.2 Components Involved

Exhibit 2.2 summarizes the key activities involved in the operation of the demonstration, ranging from the activities of suppliers (fuel, engines, in-vehicle components and stationary equipment), to those of government regulators (such as those responsible for safety regulations regarding vehicle conversion and fuel storage and for fire control), to the activities conducted by Commission personnel involved in management, engineering, training, bus maintenance, operation, reporting of data and analyses.

2.3 Financing of the Demonstration

The propane bus demonstration was cost-shared by Energy, Mines and Resources Canada, the Ontario Ministry of Energy and by OC Transpo. The budget and expenditures for the 3 phases totalled \$1,656,000:

Phase 1	\$1,122,000
Phase 2	495,000
Phase 3	<u>39,000</u>
Total	<u>\$1,656,000</u>

The Ministry of Transportation, Ontario funded certain additional subcontracts for propane and diesel engine evaluation and optimization.

ACTIVITIES IN DEMONSTRATION

Engine, Fuel Systems, Test Equipment, Garage Changes:

- Planning
- Specifications
- Vendor Selection
- Re-engineering
- Procurement
- Installation

Safety Manuals and Revised Practices:

- Staff Training
- Revised Operations
- Revised Maintenance
- Cost and Job Accounting

Operations:

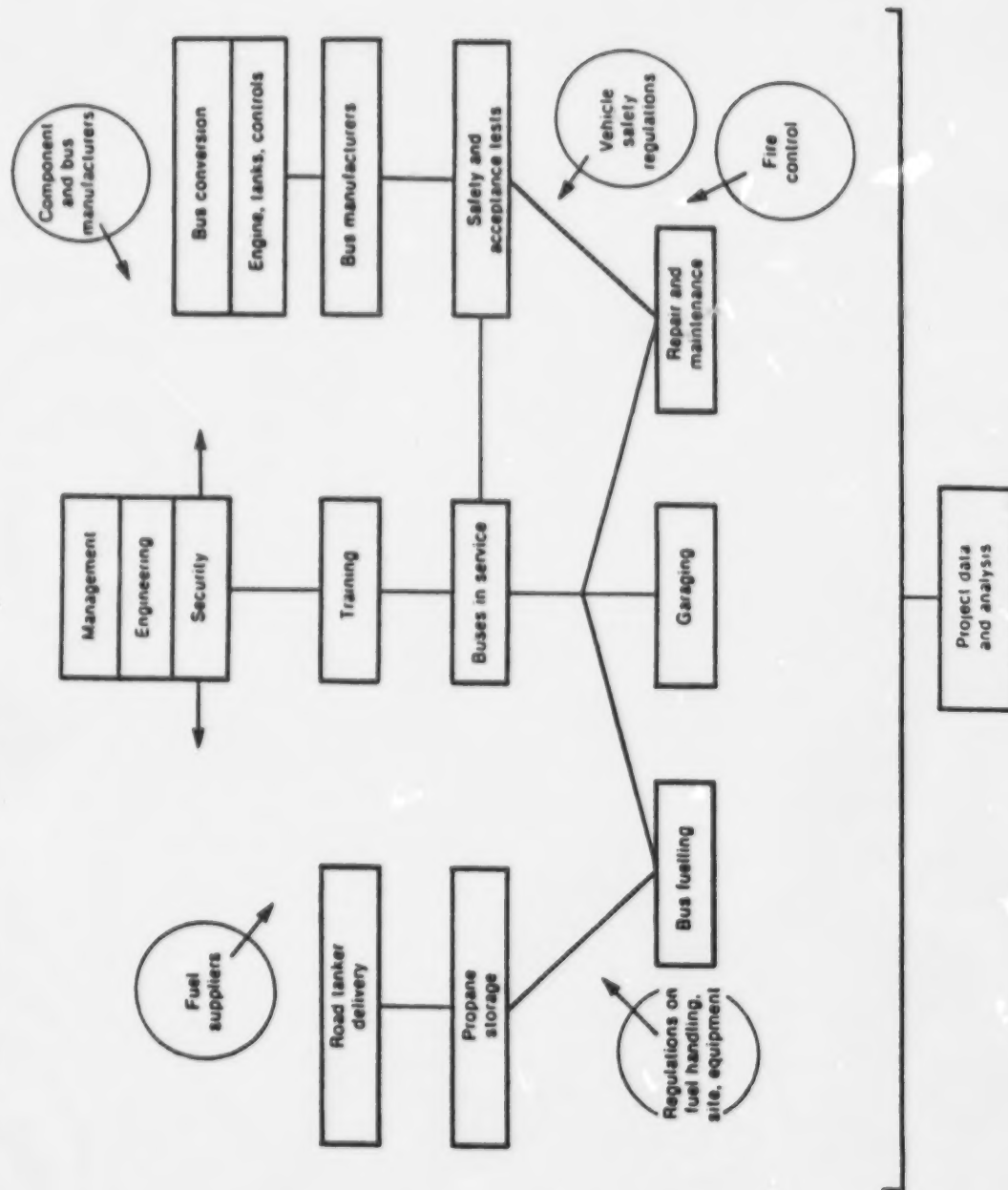
- Component Tests
- Go/No-Go Tests on Buses (including conventional base line)
- In-Service Operations, Inspections, Maintenance
- Back-Up Research/ Testing/Optimization
- Data Collection and Interpretation (Cost/Performance/Safety)
- Daily Management

Information Transfer:

- Demonstrations/Ceremonies/Publicity
- Exhibition and Reports to Public, Industry, Sponsors
- Steering Committee and Technical Meetings

Exhibit 2.2

DEMONSTRATION COMPONENTS



2.4 Organization of the Demonstration (see Exhibit 2.3)

The demonstration was managed by a Steering Committee composed of representatives of OC Transpo, EMR Canada, the Ontario Ministry of Energy (MOE), the Ontario Ministry of Transportation (abbreviated to MTO in this report), with the services of an independent consultant retained as secretary and a technical resource. The Chairman of the Committee was the General Manager of OC Transpo.

MTO provided management assistance at the total demonstration level and OC Transpo provided the operating management of the project, for which a project manager was assigned by OC Transpo from the Equipment Department. The suppliers, consultant and OC Transpo project staff reported to the General Manager of OC Transpo through the project manager and the Equipment Department. In addition, MTO assisted the project manager in technical matters and in liaison with other technical groups, such as the Ontario Research Foundation and equipment developers.

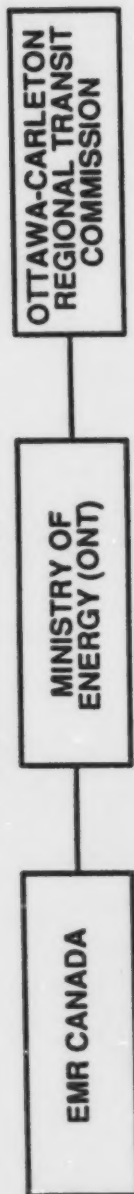
All parties to the demonstration agree that the organization and management of the project were appropriate and productive.

2.5 Preliminary Evaluation

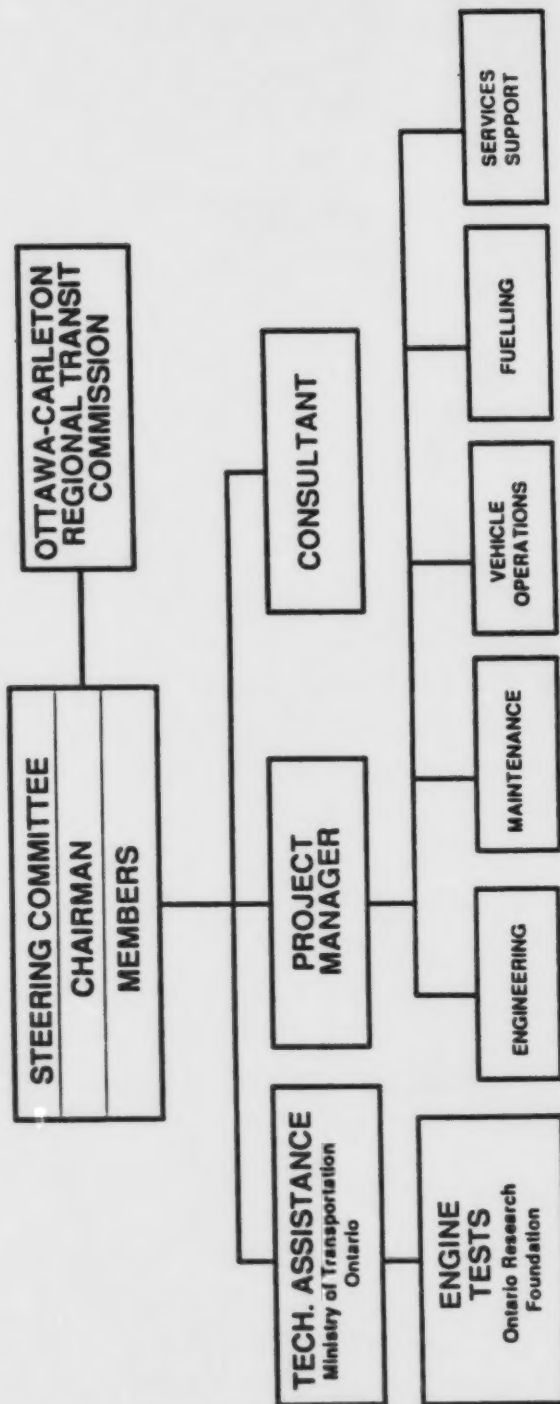
The preliminary evaluation showed that propane supply and cost projections were favourable (see Appendix 2) and that conversions could be profitable if the bus conversion cost could be amortized over a number of years. The long life (12-18 years) of city buses, the ease of engine replacement in GM-type buses, the high annual mileage and fuel consumption of buses and the fact that fuelling is conducted at day's end at centralized refuelling centres contributed to the positive evaluation of propane bus conversion.

ORGANIZATION FOR PROPANE DEMONSTRATION

Major Funding From



Project Management



Existing OC Transpo Operations

In addition, it was foreseen that the problems with diesel fuel - cost increases, quality deterioration, anticipated air pollution and noise control legislation - could favour future use of propane buses. An evaluation of the benefits of propane conversion is given in Section 9 "Economics of Propane Operations".

2.6 Search for Technology and Suppliers

2.6.1 Selection of Engine Type

In 1982, when the search for propane bus engines began, it was decided not to pursue the conversion of gasoline engines to propane, due to the anticipated short life of such high-speed engines in transit service compared to diesel engines and the experience of the Chicago Transit Authority, San Jose (California) Transit and propane distributors with gasoline-based engines. Also, despite the low initial and replacement cost of gasoline engines compared to diesel engines of the required 170-200hp output, it was apparent that certain N. American engine manufacturers planned to phase out large gasoline engine manufacture in favour of diesel engines. International Harvester (now Navistar) and Ford have since taken this step and sources of potentially suitable gasoline engines are now restricted.

Two possible routes were identified for the production of propane engines based upon conversion of compression ignition (diesel) engines:

- i. The dual-fuel route, in which part of the diesel fuel is replaced by propane introduced with intake air ("aspirated" propane) or by addition of a propane injection system to that already installed in the engine for diesel fuel. These routes retain compression ignition of the fuel/air mixtures.
- ii. The mono-fuel route, in which diesel fuel is totally replaced by propane. In this embodiment of the propane engine the diesel fuel

Injection and compression ignition system is replaced by a propane/air mixer (carburetor) and combustion of the fuel/air mixture in the cylinders is initiated by a spark-ignition system (spark plug, ignition coil and distributor). The resulting system is similar to that created in the conversion of gasoline (Otto cycle) engines to propane.

The advantages and disadvantages of the options are summarized in Exhibit 2.4. The perceived balance of these advantages led to the selection of the mono-fuel spark-ignition system as the first choice for the OC Transpo demonstration. It was noted that Vienna Transit had concentrated its recent bus purchases on the mono-fuel system to minimize costs and the use of diesel fuel.

2.6.2 Engine Acquisition

All N. American manufacturers of heavy duty highway diesel engines and selected European companies with propane engine experience were invited to bid on the supply of one propane engine, collaboration in a GO/NO-GO acceptance test of the engine in a GM bus, to be followed, if successful, by purchase of 16 more engines and the services needed to train OC Transpo staff in the re-engining of 15 buses, engine maintenance and repair. The specifications required the engine to be interfaced with the Allison V730 transmission system and housed transversely in the small engine compartment of 1979 versions of the "New Look" GM bus. The major problems for manufacturers were:

- . absence of efficient technology for conversion of GM 2-stroke diesel engines to propane required adoption of a 4-stroke engine for propane service
- . small size of the engine compartment in the GM bus (the 2-stroke is a compact V-6 engine)

Exhibit 2.4

Propane Engine/Conversion Selection - Otto Cycle versus Dual Fuel Systems

ADVANTAGES

OTTO CYCLE (100% propane)

Total replacement of diesel fuel by propane with full implementation of demonstration strategy (oil substitution and fuel diversification)

Use of only one fuel simplifies procurement, bulk and in-vehicle storage operations

Potential lower cost of carburetion system compared to fuel injection system (high pressure and fuel volume precision required in injection systems)

DISADVANTAGES

Lack of familiarity of mechanics at OC Transpo (and most Canadian transit properties) with maintenance requirements of spark-ignition systems

Initial requirement to maintain inventories of components for both diesel and propane engines

Difficulty anticipated in re-converting dedicated engines to use diesel fuel, should that be required

DUAL-FUEL SYSTEM

Few alterations to engine required: engine retrofit possible

Mixed fuel system with propane aspiration permits fuel composition to be varied to optimize fuel consumption and power output

Return to full diesel operation in emergencies possible

Continued use of diesel fuel

Only 30% substitution of diesel in systems where propane is aspirated with air into cylinder before diesel is injected. Up to 80-90% substitution of diesel possible in pilot-injection systems

Low efficiency of pilot-injected engines at low loads: compression ratio needed to avoid engine knock with propane not optimized for diesel operation

Only partial reduction of particulates (smoke) and odour in engine exhaust

Inherently high cost of dual-fuel pilot injection systems: two injection systems required

- . unique counter-clockwise direction of rotation of the GM engine and the requirement for interfacing the propane engine with the Allison transmission designed for reverse rotation engines
- . location of the carburetion equipment, ignition and other accessories for accessibility, notwithstanding the reverse rotation requirement.

No bids were received from N. American diesel engine manufacturers and a contract was awarded to Dereco of Arbon, Switzerland, which had already supplied propane engines and converted buses in Switzerland. The Dereco engines were spark-ignited and based on conversion of 4-stroke, 6 cylinder (in-line configuration), 9.6 litre diesel engines supplied by Iveco (a division of FIAT, the majority owner of Dereco). The selection and interfacing of the propane carburetion and spark-ignition systems were the responsibility of the engine supplier.

Dereco staff, together with staff from OC Transpo and Hovey Industries Ltd. of Ottawa, undertook the engineering changes needed to the engine cradle, exhaust, air and cooling systems: the outcome being that installation and removal of the propane engine is now no more complex than that of a conventional diesel engine.

2.6.3 In-Vehicle Fuel Tanks

No off-the-shelf propane storage tank was available to meet the requirement that sufficient propane be stored to provide a range of not less than 700 km. Such a range permits the propane buses to be used throughout the OC Transpo system, including 24 hour service on the longest suburban run.

Work with Westeel of Winnipeg led to the design of a propane storage system in which four conventional tanks are manifolded in the liquid and vapour phase to form a single preassembled 800 litre (water

volume) capacity tank equipped with all the gauges and main valves assembled for rapid refuelling and inspection from one position at the side of the bus. The assembly includes under-tank protection from road hazards, such as manhole covers. A number of corrosion protection coatings were evaluated to select the final coating. As required by Ontario and Canada-wide safety regulations, the tanks are equipped with a mechanical float contents gauge and "splitter"-type valve to ensure that the tanks are not filled beyond the 80% of water capacity level.

2.6.4 Propane Supply, Storage and the Refuelling Facility

A competitive bid process resulted in the award of the propane supply contract for Phase 1 to Superior Propane Ltd., who within the supply contract, also provided use on site of a two tank, above-ground propane storage facility and an island-type propane dispenser located close to the main garage entrance. Superior continued to supply propane by road tanker during Phases 2 and 3 of the demonstration.

2.6.5 Comparative Engine Tests

Contracts were placed with the Urban Transportation Development Corporation (UTDC) and with the Ontario Research Foundation (ORF) for comparative testing of the GM 6V.71N engine (the "standard" Canadian bus engine), an Iveco 4-stroke diesel engine and the Iveco propane engine, based on conversion of the Iveco diesel engine. The ORF work was later extended to include comparative measurements of engine performance and exhaust emissions. The tests at UTDC and part of the ORF tests were funded within the demonstration budget, but additional funding was provided by MTO to extend the ORF tests.

2.7 Data Collection Analysis and Reporting

Data was collected on the propane buses throughout Phases 1,2 and 3 and on a fleet of 10 GM diesel buses of the same vintage and model in

Phase 3.

The importance of data collection, analysis and reporting was recognized at the outset of the demonstration and substantial resources were allocated to these tasks. The scope of the data and reporting activities is illustrated in Exhibit 2.5.

To facilitate the process a system was developed for the daily collection of operating detail and monthly assembly of data on the content, frequency and cost of maintenance, and inspection of the propane bus fleet and fixed facilities. The data collection was extended in Phase 3 to include a fleet of 10 GM diesel-fuelled buses of the same configuration and vintage as the propane bus fleet.

The data was entered on a microcomputer programmed to store and calculate monthly and year-to-date summaries. The summaries provided operating information, such as the kilometers travelled, bus availability and fuel consumed, as well as total costs and costs calculated on a dollar per kilometer basis. Data on vehicle kilometers and fuel consumption was also provided in graphic form. The operation of this simple computer-based system is described in the manual "Operating Instructions for the Propane Demonstration Data System" in Appendix 3. The list of reports routinely generated is illustrated in Exhibit 2.6. The format of the daily input form and of the typical monthly and year-to-date reports are illustrated in Exhibits 2.7 and 2.8. Other reports generated during the demonstration are listed in Exhibit 2.9.

Exhibit 2.5

DATA COLLECTION AND REPORTING

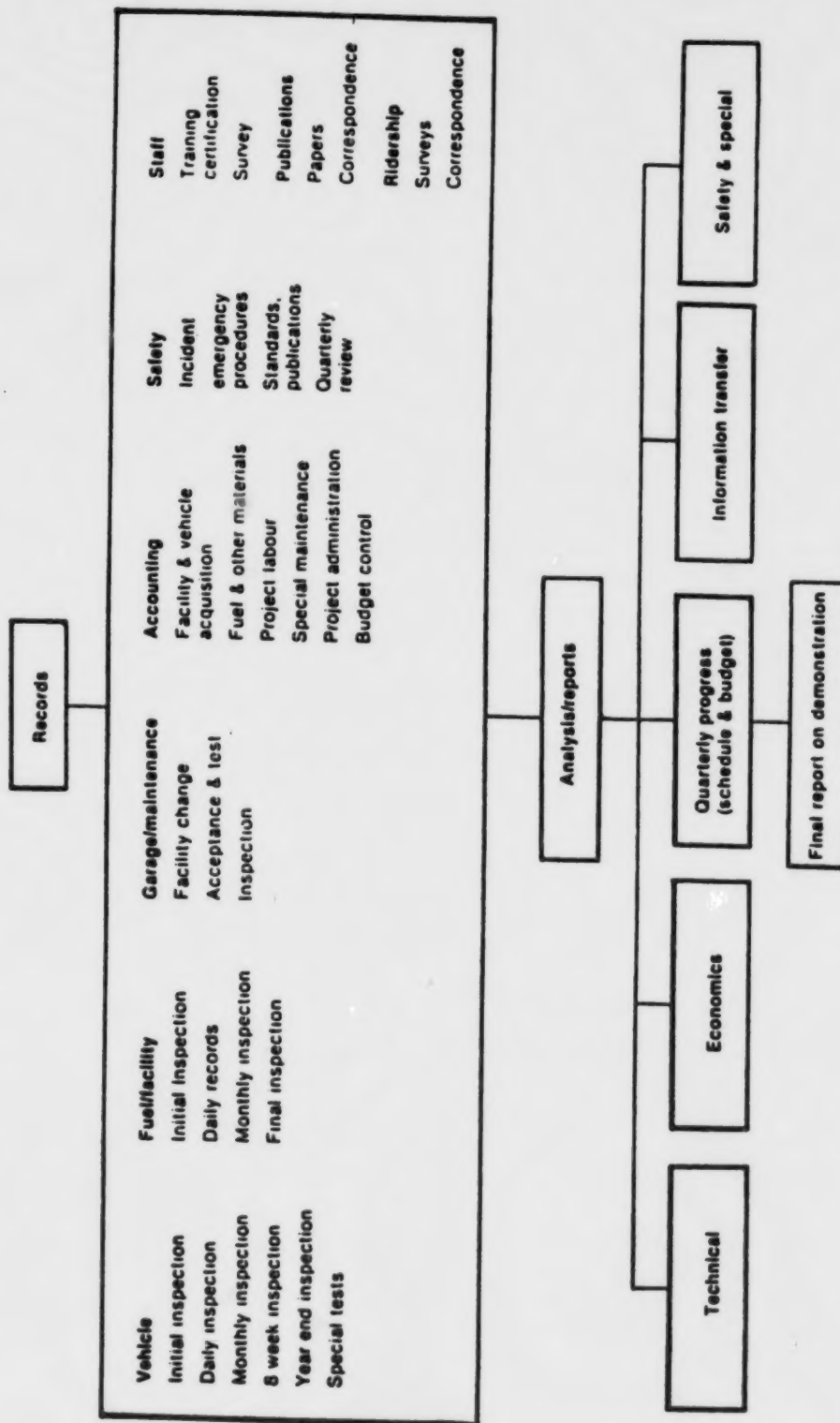


Exhibit 2.6
Reports Generated by Propane Demonstration Data System

***DATA COLLECTION AND REPORTING
SYSTEM DAILY INPUT FORM***

***VEHICLE MONTHLY AND YEAR-TO-DATE
OPERATIONS REPORTS***

***VEHICLE MONTHLY AND YEAR-TO-DATE
MAINTENANCE REPORTS***

MONTHLY PROPANE FACILITY REPORT

***MONTHLY VEHICLE
SAFETY CHECK REPORT***

***MONTHLY GARAGE
SAFETY CHECK REPORT***

DAILY INPUT FORM

Bus Number	7917	7922	7923
Date of Entry(yymmdd)	860602	860602	860602
Hubometer Reading (km)	0	106316	54263
Fuel Added (litres)	0	301	312
Refuelling (fill-up) (#)	0	1	1
Engine Oil Added (litres)	0	0	0
Antifreeze Added (litres)	0	0	0
Front Tires Replaced (#)	0	0	0
Transmission Oil Added (litres)	0	0	0

Exhibit 2.8

VEHICLE MONTHLY AND YEAR-TO-DATE OPERATIONS REPORTS

MONTHLY		FLEET TOTAL	
Bus Number	7917	7922	
Date of Entry (year/mo)	8/04/30	8/04/30	
Mileometer Reading (km)	794	112674	417699
Kilometre Reading (ft)	293	4358	36541
Fuel Added (litres)	347	5892	33262
Fuel Economy (litres/100km)	118.43	92.67	91.03
Fuel Cost (\$)	\$63.65	\$1,084.10	\$6,120.21
Fuel Cost/100 km (\$)	\$21.79	\$17.35	\$16.75
Retuelling (fill-up) (ft)	3	24	155
Refuelling Cost (\$)	\$9.00	\$72.00	\$465.00
Refuelling Cost/100 km (\$)	\$3.07	\$1.13	\$1.27
Engine Oil Added (litres)	0	9	52
Oil Use (litres/100km)	0.00	0.14	0.14
Oil Cost (\$)	\$0.00	\$11.43	\$66.04
Oil Cost/100 km (\$)	\$0.00	\$0.18	\$0.18
Antifreeze Added (litres)	0	0	0
Antifreeze Use (litres/100km)	0.00	0.00	0.00
Antifreeze Cost (\$)	\$0.00	\$0.00	\$0.00
Antifreeze Cost/100 km (\$)	\$0.00	\$0.00	\$0.00
Front Tires Replaced (ft)	0	2	3
Tire Cost (\$)	\$0.00	\$1,200.00	\$1,600.00
Tire Cost/100 km (\$)	\$0.00	\$18.87	\$4.93
Transmission Oil Added (litres)	0	0	0
Transmission Oil Use (litres/100km)	0.00	0.00	0.00
Transmission Oil Cost (\$)	\$0.00	\$0.00	\$0.00
Transmission Oil Cost/100 km (\$)	\$0.00	\$0.00	\$0.00
SUMMARY MONTHLY OPERATING COSTS			
OPERATIONS COST (\$)	\$72.85	\$2,367.53	\$8,451.25
OPERATIONS COST/100 km	\$24.86	\$37.24	\$23.13

Exhibit 2.8 continued

VEHICLE MONTHLY AND YEAR-TO-DATE OPERATIONS REPORTS

YEAR-TO-DATE	7Y17	7Y22	FLEET TOTAL Y.T.D.
Kilometre Reading	293	28445	207118
Fuel Added (litres)	347	32676	245706
Refuelling (fill-up) (#)	3	130	886
Engine Oil Added (litres)	0	57	415
Antifreeze Added (litres)	0	22	94
Front Tires Replaced (#)	0	2	6
Transmission Oil Added (litres)	0	2	18
Fuel Economy (litres/100km)	118.43	114.79	118.67
Fuel Cost (\$)	\$63.85	\$4,012.38	\$45,726.62
Fuel Cost/100 km (\$)	\$21.79	\$21.12	\$21.84
Refuelling Cost (\$)	\$9.00	\$390.00	\$2,658.00
Refuelling Cost/100 km (\$)	\$3.07	\$1.37	\$1.28
Oil Use (litres/100km)	\$0.00	\$0.20	0.20
Oil Cost (\$)	\$0.00	\$72.39	\$527.05
Oil Cost/100 km (\$)	\$0.00	\$0.25	\$0.25
Antifreeze Use (litres/100 km)	0.00	0.05	0.05
Antifreeze Cost (\$)	\$0.00	\$26.38	\$121.26
Antifreeze Cost/100 km (\$)	\$0.00	\$0.10	\$0.06
Tire Cost (\$)	\$0.00	\$1,200.00	\$3,600.00
Tire Cost/100 km (\$)	\$0.00	\$4.22	\$1.76
Transmission Oil Use (litres/100 km)	0.00	0.01	0.01
Transmission Oil Cost (\$)	\$0.00	\$2.08	\$18.72
Transmission Oil Cost/100 km (\$)	\$0.00	\$0.01	\$0.01
SUMMARY YEAR-TO-DATE OPERATING COSTS			
OPERATIONS COST Y.T.D.	\$72.85	\$7,705.23	\$52,149.65
OPERATIONS COST/100 km Y.T.D.	\$24.84	\$27.07	\$25.18

OTHER REPORTS ISSUED

Management/Administration

Final Report
Executive and Technical Summary
Annual Reports
Quarterly Reports
Minutes of Steering Committee Meetings
Major Correspondence

Technical Reports

Road Call Reports/Service Records
Driver Survey
Engine and Bus Status Reports
Fuel Costs and Forecasts
Technology Reviews (N. American, European)
Technical Service and Fault Analysis
Safety Manual
Safety Incidents

Information Transfer

Publicity
Publications and Presentations

3. BUS CONVERSIONS TO PROPANE

3.1 Rationale for Conversion of Existing GM Buses

Two options for the acquisition of propane buses for the demonstration were considered:

- i. purchase of new buses specifically designed for propane
- ii. retrofitting of existing buses with propane engines and fuel systems.

Acquisition of new buses specifically designed for propane was considered to be appropriate for future purchase after the problems and benefits of a propane operation were identified. At that point new buses would provide cost savings and environmental benefits throughout the 14-18 year life of new buses. New propane buses would need to be designed to Canadian standards requiring extensive design and testing, including crash tests.

Since the objective was to gain information on the future potential for propane and a comparison with existing diesel-fuelled buses, it was decided that the most expeditious and economic route would be to convert 40ft. GM buses to propane. Further rationale for the retrofit route included:

- . familiarity of the OC Transpo staff with the GM bus
- . advantage of a close comparison of propane and diesel engines in the same bus type
- . propane buses would be reconverted to diesel operation, if required, at the termination of the demonstration
- . retrofit of existing GM buses could provide an early opportunity to save diesel fuel and use propane.

The majority of buses in the OC Transpo fleet and of other transit

properties in Canada and the U.S. were 40ft. GM buses equipped with the Detroit Diesel Allison (DDA) 2-stroke engine. Furthermore, the compact DDA V-6 engines were also widely used by other N. American transit bus and certain truck and intercity coach manufacturers. The demonstration of a refitting with a propane engine could therefore be significant throughout N. American bus properties.

OC Transpo had 30 GM "New Look" buses of 1979 vintage in service, which were considered suitable for conversion to propane. Of these, 10 were converted to propane and 10 of the remaining diesels were monitored to provide a baseline for propane bus measurement. A particular advantage of the "New Look" GM buses was their monocoque construction which provides ample under-bus space for propane storage tanks. The more recent GM "Classic" bus design retains this advantage. The principal disadvantages of the GM buses were the small size of the engine compartment and the requirement to purchase engines with unique reverse rotation, if the Allison V-drive transmission was to be retained.

3.2 Engine Conversion to Propane by Dereco

Conversion of the basic Iveco naturally aspirated 4-stroke, 6 cylinder, 9.6 litre diesel engine to a spark-ignition engine involved the following:

- . modification of the engine crankshaft rotation from the standard counter-clockwise rotation (viewed facing the flywheel) to clockwise rotation for compatibility with the V-730 Allison transmission which was retained in the GM buses and interfaced with the engine through an adapter
- . replacement of the diesel system by a spark-ignition system: a distributor and vacuum governor were fitted in place of the diesel fuel pump; spark plugs were used in place of the fuel injectors

- . addition of a commercially available propane fuel/carburetion system comprising a filter/fuel lock assembly, a convertor (also termed a vapourizer which converts liquid propane to vapour), and an air/fuel mixer, also termed a carburetor: the air/fuel inlet manifold was also modified
- . the compression ratio in the combustion chamber was reduced from 17:1 to 10.9:1 to avoid engine knock
- . a heat resistant insert was added at the exhaust valve seat and stellite valves were used to avoid wear, due to the higher exhaust temperature of combusted propane compared to diesel.

The key specifications of the Iveco reverse rotation propane engine 8220.RLPG are given in Exhibit 3.1. The dimensions are given in Exhibit 3.2. See also Appendix 4.

3.3 Engine Interfacing with GM Bus Components

A dummy engine was used initially to determine the fit of the Iveco engine within the engine compartment and interfacing with the retained components of the GM "New Look" bus. Changes were made in the location and size of the cooling fan, in the exhaust system ducting, in the electrical ignition system, in the drive shaft length and in the mounting of the engine which is installed in the bus at 15° to the vertical. The engine cradle was modified to provide the same ease of engine replacement as that achieved with the GM engine and cradle.

3.4 Fuel Tank Development

The "New Look" diesel buses carry a 378 litre diesel storage tank, nominally sufficient to provide a range between refuelling of 750-800 kilometers. However, bus transit practice is to refuel the vehicle daily.

Exhibit 3.1
Specifications for the Iveco Reverse Rotation Propane Bus Engine
8220.RLPG (Data from Dereco Ltd.)

1. ENGINE

Dry weight	1764 lbs
Dimensions	54.96 ins
Length	25 ins
Width	37.83 ins
Height	
Bore	800 kg
Stroke	1396 mm
Capacity	635 mm
Compression ratio	961 mm
Firing order	125 mm
Rotation	130 mm
Nominal speed	9.572 litres
Nominal power	10.9:1
Max. torque	1-4-2-6-3-5
Speed at max. torque	Clockwise (view from flywheel)
Brake specific fuel consumption at 2100 rpm	2100 rpm
	127 kw
	678 Nm, 69 mhp
	1000 rpm
	0.29L/hp hour (10 MJ/kwh) 7.46 MJ/hp hour
	0.28L/hp hour (9.7 MJ/kwh) 7.24 MJ/hp hour
	170 hp
	500 ft.lbf

2. VALVE TIMING

Inlet open	9° before Top Dead Centre (TDC)
closed	51° after Bottom Dead Centre (BDC)
Exhaust open	48° before BDC
closed	15.5° after TDC
Valve clearance	0.25 mm
Cold engine	0.50 mm
Inlet	
Exhaust	

3. PISTON

Type	Similar to Diesel version in general
Combustion chamber	Heron, with a volume of 135.8-140.2 cm ³
Piston/cylinder head cold clearance	1.80-1.90 mm

Exhibit 3.1 continued

4. FUEL SYSTEM

Fuel
Filter/fuel lock valve
Vapouriser
Vap.-spring
Carburetor
Governor

Propene: HD5
IMPCO VFF 30
IMPCO Model E EOS-20(0)
Reduced from original
IMPCO CAG 425-20-4, V2-19 (4 holes)
Holly-base (pneumatic flyweight governor on distributor shaft actuates throttle)
2190-2200 rpm

Governed speed

5. IGNITION SYSTEM

Voltage
Electronic box
Coil
Distributor
System-drawing
Spark plug
Gap
Ignition timing 600 rpm
2100 rpm

12V
Bosch O 227 100 033
Bosch O 221 122 303
Bosch B 237 360 275
Bosch A 227 019 190
Bosch W2CC
0.4 mm (max. 0.6-0.7 mm)
3-6° before TDC (as delivered; modified during demo.
16-20° " " " " " "

6. INLET/EXHAUST SYSTEM

Exhaust, max. backpressure
Inlet, max. restriction

7. COOLING SYSTEM

Coolant

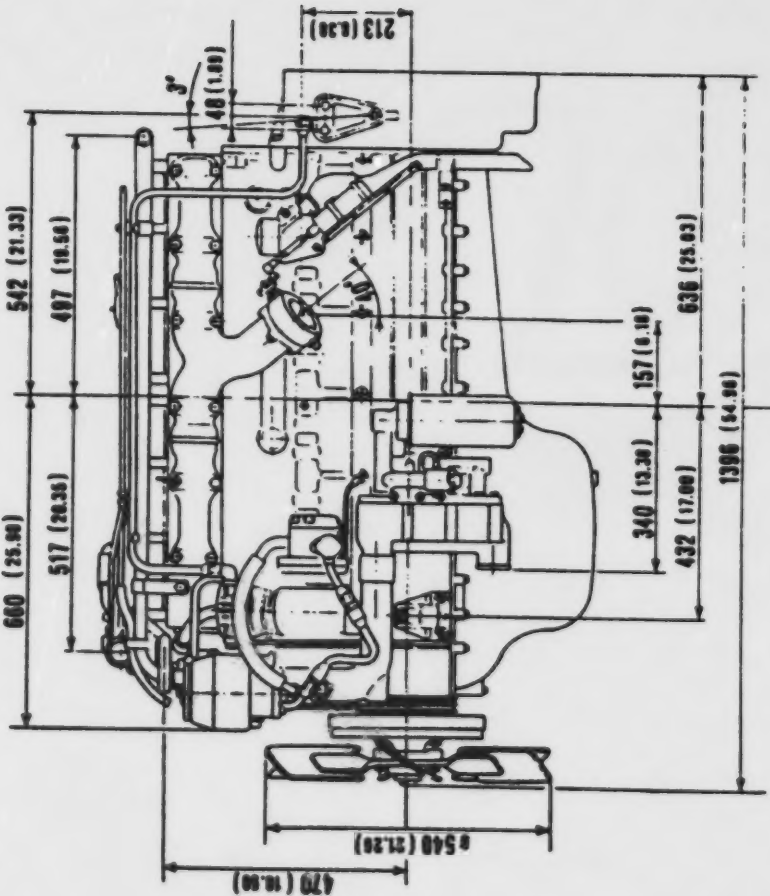
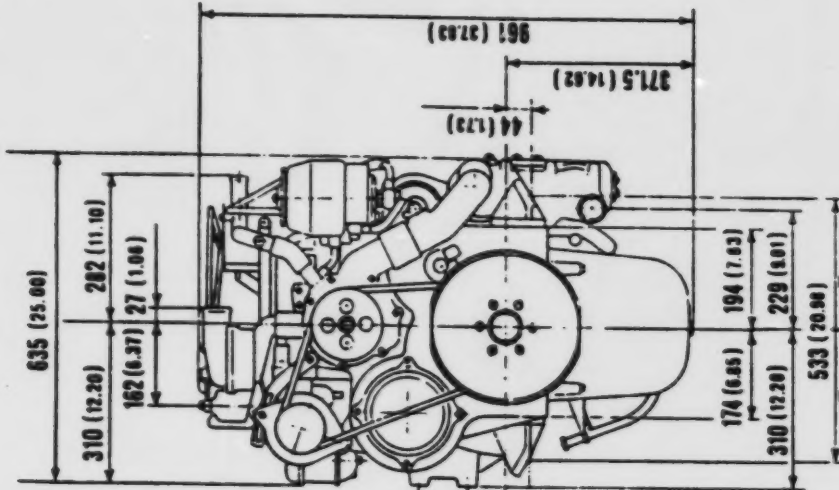
Min 33% of commercial antifreeze

8. LUBRICATION SYSTEM

Lube oil recommendation

Low ash multigrade such as Essolube G-10W-30

Exhibit 3.2



At OC Transpo, where the range between refuelling may reach 700 kilometres on the urban-suburban runs, an on-bus storage volume of 640-680 litres was therefore required (at a maximum propane/diesel replacement ratio of 1.8). This was met by the design and production by Westeel Corporation of Winnipeg of a prefabricated assembly (see Exhibit 3.3) in which 4 conventional steel propane vessels were manifolded to form a single propane tank of 800 litres water capacity equipped with a "splitter-type" filling valve to ensure that the tanks were not filled beyond the 80% of water capacity required by the Ontario and Canada propane safety codes (CAN1-B149.2 M80, unchanged in the 1986 version). The tank was protected by a corrosion-resistant coating. The favourable features of the 4 vessel tank assembly include:

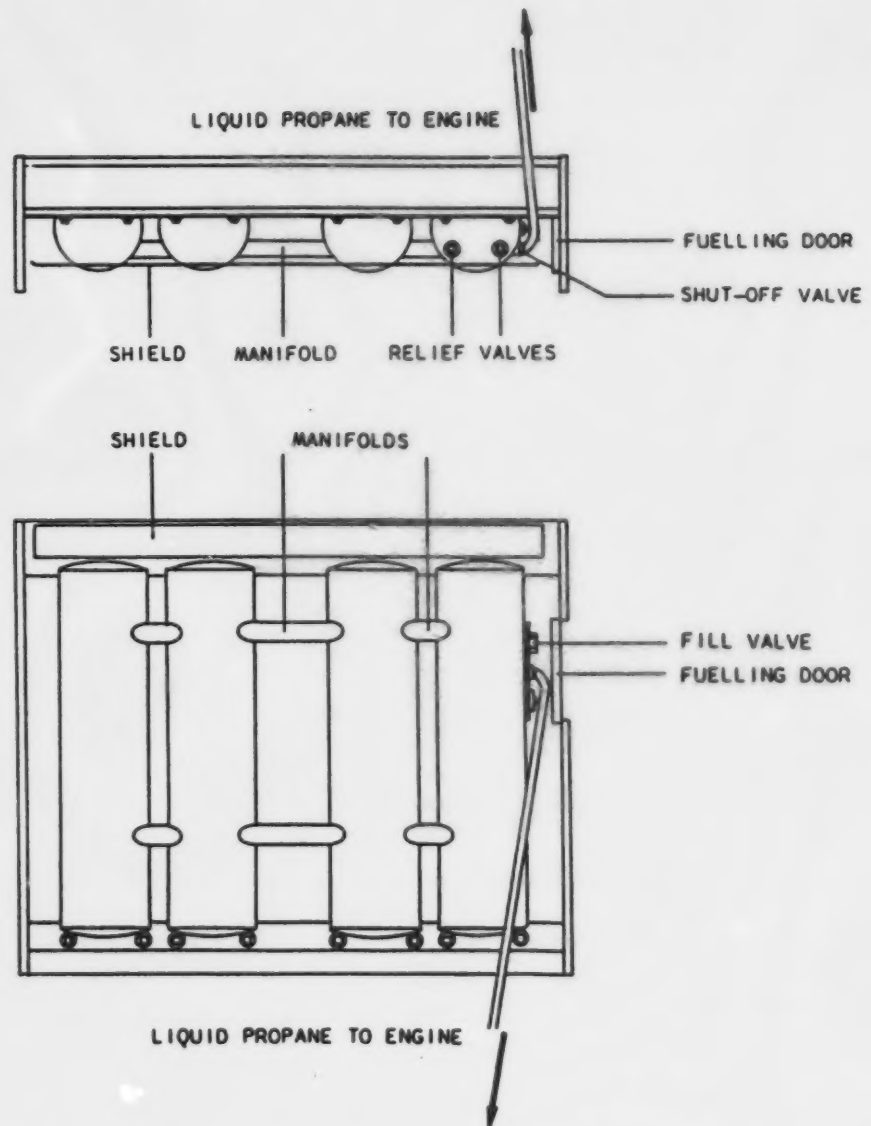
- . propane capacity of about 640 litres in one assembly
- . fast installation (bolted to underframe of bus)
- . protection of underside of the vessels from road hazards, such as manhole covers, ice, rocks, etc.
- . only one set of gauges and main valves is required, since the manifolding essentially creates one tank
- . gauges and main valves are located at one position under a hinged cover at the side of the bus: fast access for refuelling and inspection is thus provided.

The design permits incorporation of a duplicate set of refill valves at either side of the vehicle.

3.5 Other Components, Installation

The manufacture of the fuel tank assembly was subcontracted to Westeel Corporation. Production of other engine supports and interface components was by Hovey Industries Ltd. of Ottawa.

Exhibit 3.3
The Bus Fuel Tank System



3.6 In-House Tests and Test Equipment

OC Transpo and other transit bus properties routinely use a bus dynamometer to measure the power output of diesel buses. Power measurements at selected engine speeds are used to determine whether bus engines need service. The same equipment and technique are used to evaluate the power output of propane engines, but tests and engine set-up in the case of spark-ignition propane engines are somewhat more complex than for diesel engines. Additional equipment was purchased to measure ignition timing (and to set the spark advance) and composition of exhaust gases. The analyzer chosen measures the unburned hydrocarbon, carbon monoxide and oxygen levels in the engine exhaust when the engine is tested on the dynamometer.

Since the exhaust gas analysis equipment was purchased, the whole technology of exhaust gas analysis and engine control has advanced. Catalysts, oxygen sensors in the exhaust stream and electronic engine controls are now used not only with gasoline engines, but also in propane engines for automobiles. Commercial use of these systems in large propane engines is now beginning, but such systems have not yet been tested or adopted for use in the OC Transpo propane bus fleet.

3.7 Manufacturer's Tests of the Propane Engine

Although the spark-ignition propane engine cannot match the rated power of the diesel engine from which it is derived, the overall performance of the propane engine can be made to equal or exceed that of the diesel by taking advantage of the enlarged full-load speed range and the high torque available at low engine speeds. This capacity was used by Dereco to simultaneously meet three key requirements of the propane engine specification set by OC Transpo:

- i. power output of not less than 170hp at 2100rpm using the Allison transmission

- ii. low fuel consumption - less than 1.8 times the volume of diesel fuel
- iii. pollution control to the prevailing Canada standards.

The optimum balance between these was attained by selection of a high (10.9:1) compression ratio, a slightly lean air-to-fuel ratio (1.1:1.3 x stoichiometric) and selection of the ignition timing. Engine tests at Dereco indicated that the engine specification had been met or exceeded (Exhibit 3.4). Further detail on performance, fuel economy, pollution and lubricant testing at Dereco is in Appendix 5.

Exhibit 3.4
Key Specifications and Factory-Measured Performance
of the Propane Engine

<u>SPECIFICATION</u>	<u>DERECO TEST RESULTS</u>
Power output exceeds 170hp at 2100 rpm	175hp at 2100rpm
Fuel consumption 1.8 times diesel (volume)	Within specification (at less than 0.3L/hphr) with factory settings maintained
Pollution control:	
Hydrocarbon and NOx less than 16g/bhphr	12.8g/bhphr (US 13 mode test)
Carbon monoxide less than 40g/bhphr	1.7g/bhphr

3.8 Static Dynamometer Tests of the First Propane Bus at OC Transpo

A condition of the supply contract was that the propane-engined buses achieve the same performance as buses equipped with the DDA model 6V-71 naturally-aspirated engine using C55 injectors. The performance tests chosen for the prototype bus conversion were a comparative dynamometer test at the OC Transpo garage, a timed test on typical routes and detailed tests on a test track.

The dynamometer test is the standard used at OC Transpo to determine engine power and for engine overhaul. It is run with the bus on the dynamometer at an engine speed of 1500rpm, corresponding to a bus speed of 41mph or 65.6kph, with the cooling fan off. Buses with less than an 80hp rating require engine overhaul.

Bus number 7930, when converted to propane, had a power reading in the dynamometer test of 95hp: this compares to 100hp on the previous test.

Records of previous diesel bus tests showed:

- . the measured hp of 42 buses of 1979 and 1980 vintage had varied from 108hp to 62hp
- . 36 of the 138 measurements on these buses had given values below 80hp, the mean of the 102 buses which exceeded the 80hp barrier was 90hp
- . 27 tests on 11 buses of 1982 vintage showed that two had not passed the 80hp barrier, the mean measured power of the remainder was 97hp.

It was concluded that the prototype propane bus had given an excellent power rating under the test conditions.

3.9 Route Tests on the Prototype Propane Bus

Measurements were taken of the total time and average speed of the prototype propane bus and a similarly loaded diesel bus of comparable power rating measured over a city route with 107 stops and a suburban route with 55 stops. The average speeds (after deducting stops) indicated a slight advantage for the propane bus:

<u>Route:</u>	<u>Average speed made good* km/hour</u>	
	<u>City</u>	<u>Suburban</u>
Diesel bus	22.21	42.3
Propane bus	23.04	43.3

* Average speed including all stops from beginning to end of route.

It was concluded that the prototype propane bus was suitable for service on city and suburban routes. The fuel consumption of the propane bus was measured at 105.8 litres/100km on the city route and 73.2 litres/100km on the suburban route. On an energy basis this is equivalent to 58.8 litres/100km and 40.7 litres/100km of diesel fuel respectively. The average for the total diesel bus fleet at OC Transpo in that year was about 53 litres of diesel fuel/100km.

3.10 Track Tests of the Prototype Propane Bus (March 1984)

The U.S. Department of Transportation, together with Booz, Allen and Hamilton, devised a test for transit buses known as the Advanced Design Bus (ADB) Test which is in general use. The test is normally conducted on a 2 mile test track, and involves runs over a 14 mile circuit in which the bus is accelerated to different speeds run over controlled cruise periods, decelerated and idled for defined times to simulate service conditions in a central business district, in arterial and commuter service. The test was modified to be used on a 1.75 mile test track made available by the Department of National Defence.

The prototype propane bus (#7930) and the GM diesel bus used in the dynamometer and route tests (#8239) were tested using the modified ADB test. The key results were:

- . the performance of the propane bus was almost identical to that of the diesel bus: this is illustrated by comparison of the acceleration of the two buses (Exhibit 3.5)
- . the fuel consumption of the propane bus over the given circuit was 91.4 litres/100km (3.085mpg); the diesel bus was 53.65 litres/100km (5.256mpg)
- . the volumetric fuel consumption ratio of the propane and diesel buses was 1.7: this compares with the maximum value of 1.8 required in the GO/NO-GO propane bus test specification
- . the interior noise levels measured in the stationary and constant speed conditions were substantially lower for the propane bus than for the diesel tested under the same conditions (Exhibit 3.6).

It should be noted that the difference in noise levels is large: this may not be apparent from Exhibit 3.6, since the noise measurements are expressed in the logarithmic units of decibels.

3.11 Further Comparative Engine Tests

During the demonstration period the interest in pollution control heightened and stringent new standards were set by the U.S. Environmental Protection Agency (EPA) for buses brought into operation in 1991. It is believed that the new U.S. standards will be adopted in Canada at about the same time, and that the use of gaseous fuels and perhaps methanol can provide a lower cost route to achievement of the new standards. The Iveco propane engine was designed for the earlier standards and, although capable of meeting the 1991 particulate emission

Exhibit 3.5

COMPARISON OF ACCELERATION

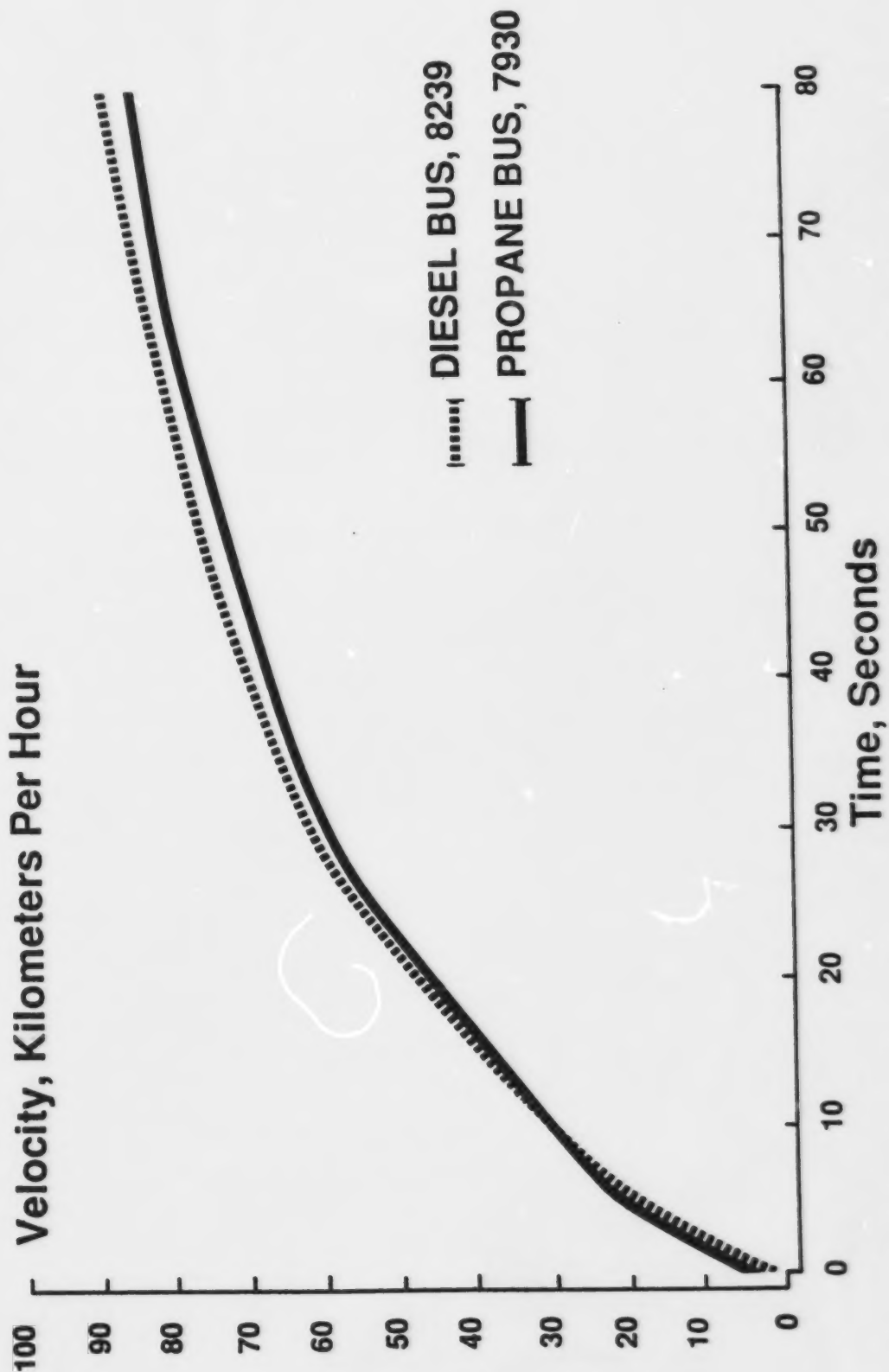
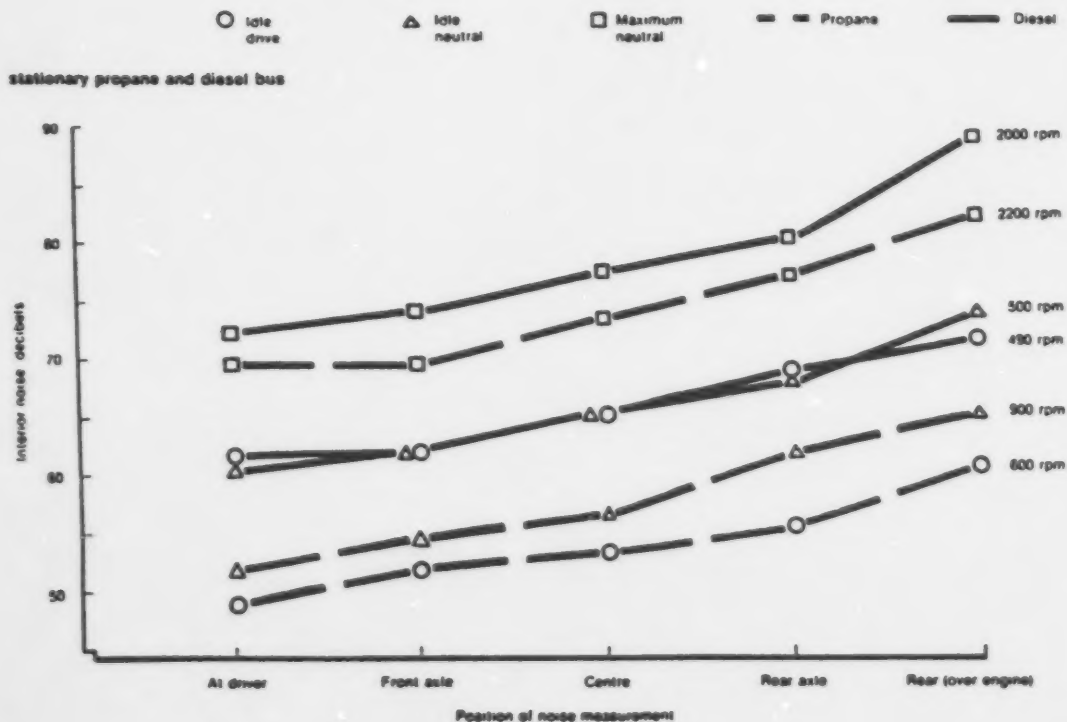
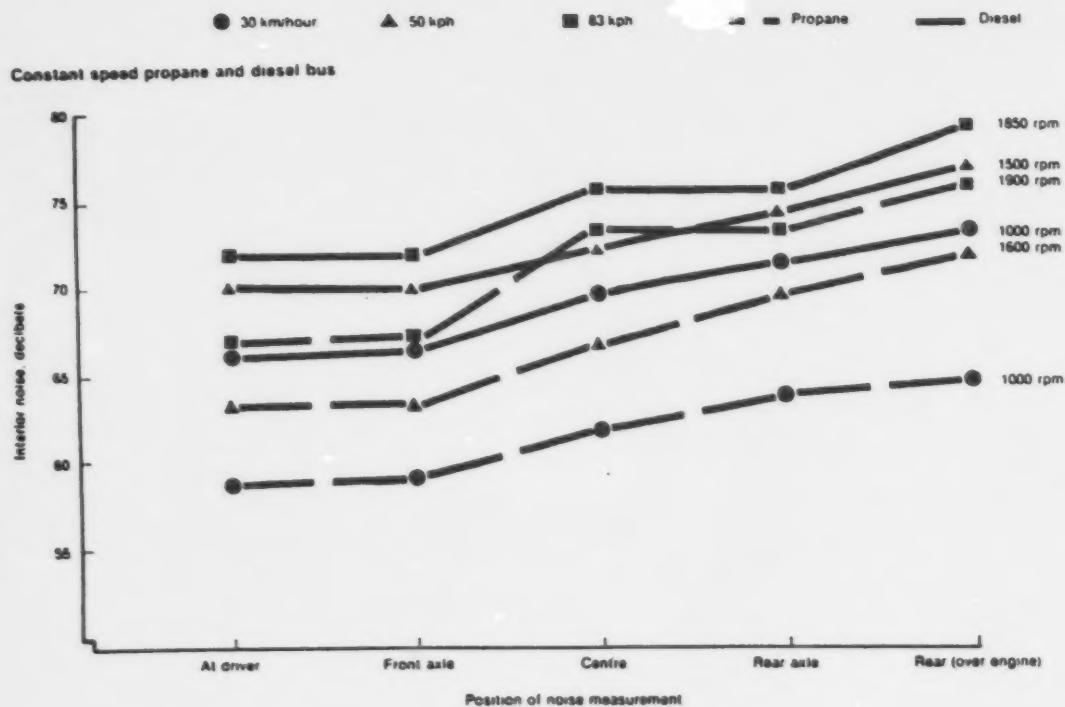


Exhibit 3.6 **Interior Noise Measurements of Propane and Diesel Bus**



levels, may require extensive modification (perhaps involving the addition of exhaust treatment devices such as 3-way catalyst systems) to meet 1991 standards for nitrogen oxides, unburned hydrocarbon and carbon monoxide.

After preliminary work on the testing of the DDA 2-stroke and the Iveco 4-stroke diesel, further testing was undertaken by the Ontario Research Foundation (ORF) and the Ministry of Transportation, Ontario (MTO) to compare the propane engine with the two diesel engines. Later, this work was extended with funding from MTO to include the Iveco natural gas engine, a spark-ignition methanol engine from M.A.N. (W. Germany) and another 4-stroke diesel engine, also from M.A.N.

Details of the ORF/MTO tests to date are recorded in Appendix 5 and those relevant to propane can be summarized as follows:

I. Steady State Tests (Characterization)

Mapping of performance of the engines using the dynamometer confirmed that the Iveco propane and diesel engines and the DDA 2-stroke engines would be expected to provide comparable performance under bus service conditions.

II. ADB Cycle Tests

The dynamometer was programmed to simulate the ADB test cycle and measurements made of the energy efficiency and exhaust emissions of the engines over this cycle. No attempt was made in these runs to optimize the performance of the engines.

The conclusions drawn on Energy Efficiency measurements are:

- the Iveco 4-stroke diesel engine exhibited the highest energy efficiency when operated over the ADB cycle

- the energy efficiency of the DDA 2-stroke diesel and the Iveco spark-ignition propane engine were lower, but similar as shown in Exhibit 3.7.

Exhibit 3.7
Efficiency Measured in the ADB Cycle Tests

	<u>Energy</u> <u>Efficiency, %</u>	<u>Efficiency Relative to</u> <u>DDA 2-stroke, %</u>
Iveco 4-stroke diesel (with reverse rotation)	36.2	116
Iveco 4-stroke S.I. propane engine	31.4	101
DDA 2-stroke diesel	31.1	100

It may be noted that the ORF dynamometer tests do not agree closely with fuel consumption measurements taken in the ADB track test. The track test indicated that the DDA 2-stroke engine was more energy-efficient than the propane engine (by about 13%); surprisingly, the ORF test showed them to be similar. Route testing of an Iveco diesel-engined bus and a DDA bus in Hamilton gave similar efficiency results to those obtained at the ORF dynamometer: the Iveco diesel-engined bus had an 8% energy advantage over the DDA bus in these measurements. These results indicate that direct comparison cannot always be made between in-bus field data and tests obtained on an engine test stand.

The conclusions drawn on the Exhaust Emission measurements are summarized in Exhibit 3.8

Exhibit 3.8
Emission Test Results Comparison
(Grams/brake horse power hour)

	<u>Particulates</u>	<u>NOx</u>	<u>Unburned Hydrocarbon</u>	<u>Carbon Monoxide</u>
<u>DIESEL ENGINES</u>				
DDA 2-stroke	0.17	10.8	1.4	1.9
Iveco 4-stroke	0.21	9.2	1.0	2.0
<u>SI PROPANE ENGINE</u>				
Iveco 4-stroke	0.015	19.2	1.2	2.1
<u>FOR COMPARISON</u>				
1991 EPA Emission Regulation for Buses - Maximum Value	0.1	5.0	1.3	15.5

Source of measurements: ORF/MTO.

The key conclusions are:

- particulate emissions measured on the propane engine during the ADB cycle test were only 10% of those measured in the exhausts from the DDA and Iveco diesel engines
- at the given engine settings the NOx emissions of the propane engine were almost twice those of the diesel engines
- at the given engine settings the level of unburned hydrocarbon emissions of the propane engine was intermediate between those of the Iveco diesel (lowest) and the DDA diesel engine (highest)
- the carbon monoxide emissions level of the Iveco propane and diesel engines were similar and somewhat higher than those shown by the DDA engine in these tests.

For comparison purposes only, the 1991 EPA emission standards are also listed in Exhibit 3.8. It should be noted that the propane engine emissions can be substantially modified by changing the engine settings and that since the EPA and ADB cycles differ, the comparison between the forthcoming EPA standard and the ADB cycle test results should be interpreted with caution.

Discussions with three propane engine suppliers (M.A.N., Daimler-Benz and Iveco/Dereco) and with experienced test laboratories (ORF and the TNO Road Research Laboratory in the Netherlands) led to the following conclusions on exhaust emissions:

- . the spark-ignition naturally-aspirated propane engine will have no difficulty in meeting the 1991 particulate emission level
- . although variations in the air-fuel ratio and the ignition timing can be used to optimize the gaseous emissions, NO_x, hydrocarbon, carbon monoxide, within acceptable engine output and exhaust gas temperature levels, it is unlikely that conditions can be found in which the propane engine can be efficiently operated within the 1991 EPA specification
- . exhaust treatment similar to that employed in gasoline engines offers an excellent prospect of meeting the 1991 emission requirements in engines operated at close to the stoichiometric air-fuel ratio. Three-way catalyst systems using measurement of oxygen in the exhaust gas coupled with electronic engine control have already been adapted for use in propane buses and are reported to conform to the 1991 EPA requirement

Alternative emission control strategies involving turbo-charged lean-burn engine techniques are under investigation. Potential exhaust emission controls are discussed in Section 7.

3.12 Bus Marking

In conformity with Ontario safety regulations, the propane buses were identified by a label "located on the inside lower right hand corner of the windshield as seen from the inside of the vehicle." In addition, the converted buses were identified by a label bearing the word "PROPANE" located near the front entrance to the bus and signage within the bus identifying the sponsors of the demonstration.

4. INSTALLATION OF THE FUEL STORAGE AND REFUELLING FACILITY

4.1 Cost-Sharing of the Equipment

Superior Propane Ltd. submitted the low bid for the supply of propane for Phase 1. They supplied propane throughout the demonstration. In addition, they provided bulk storage tanks and a dispenser at no charge, and advice which assisted the safe start-up of the fuelling operation including:

- . procurement of approvals for installation from the Fuels Safety Branch of the Ministry of Consumer and Commercial Relations Ontario, and from the City of Ottawa
- . technical service and training of OC Transpo employees in the safe handling and transfer of propane
- . propane analyses.

OC Transpo supplied concrete foundations, electrical requirements, protection and illumination within the demonstration budget.

4.2 The Facility

Two steel storage tanks each of 2,000 U.S. water gallon capacity, complete with pump, motor and valving were installed according to Ontario regulations and Canada standard CAN1-B149.2-M80. As required, the tanks were designed to be filled to 80% of the internal volume and can therefore store about 12,000 litres of propane, equivalent to about 7 days' supply for a fleet of 10 propane buses.

A temperature-compensated propane dispenser and meter was also installed to meet the 4 minute per bus refuelling time with the following safety features:

- . dispensing components are enclosed in locking cabinets

- . pump is automatically shut down in the event of propane line rupture
- . piping system at the base of the metering cabinet includes excess flow valves in both propane liquid and vapour lines
- . piping system is secured to a pull-away stand to create a break-away point and product spill control in the event of a collision
- . fuel dispensing base contains a break-away assembly which provides a positive shut-off if a bus is driven away with the refuelling line attached
- . thermal shut-down is activated by excessive heat in the dispensing area
- . "dead-man" electrical switch is provided to prevent the operator from leaving the refuelling point during refuelling
- . hose end filler nozzle is designed to prevent propane flow, unless it is properly connected to the filler valve located at the bus storage tank.

4.3 Other Safety Features

Safety regulations and required practices for propane storage and transfer at the OC Transpo location were documented in a safety manual prepared for OC Transpo with funding provided by Transport Canada. The safety manual reproduced as Appendix 6 is based upon an analysis of the Canadian safety legislation, world-wide experience with propane and the particular experience in Vienna, Amsterdam, Chicago and San Jose in the operation of fleets of propane buses.

4.4 Status of the Fuelling Facility

There have been no major spills of propane, no fires, no injuries, nor other safety incidents involving propane storage and bus refuelling.

No significant downtime due to equipment failure has been

encountered; the propane transfer pumps have required minor service on three occasions in over 36 months of service.

Winter weather conditions required the installation of a kiosk at the dispensing site.

The major problem anticipated was bus refuelling time, but the system is routinely providing a 4-minute bus refuelling time (average fill 250 litres in 1987) from one nozzle. Plans to install two-point filling of each bus were therefore not activated.

4.5 Fuel Quality

The durability and performance of propane engines is dependent upon the quality of the fuel. For example, occurrence of engine knock in high compression propane engines is influenced by the proportion of low octane components in the fuel, such as butane and propylene. Engine corrosion is influenced by the sulphur content of the fuel, since sulphur compounds, when combusted in the engine, produce corrosive sulphuric acid. Superior Propane provided occasional analyses of the HD.5 propane supplied. Exhibit 4.1 gives a comparison of typical product with the Canada standard for automotive propane CAN2-3.14-M78.

No problems attributable to fuel quality were encountered in the demonstration period.

Exhibit 4.1

Propane Quality and Canada Standard Specification

	<u>Canada Standard</u>		<u>Product Supplied</u>	
	<u>Min.</u>	<u>Max.</u>	<u>1984</u>	<u>1985</u>
<u>COMPOSITION, LIQUID VOLUME %</u>				
Propane	90	-	94.9	96.1
Propylene		5.0	0.2	0.2
Butane and heavier hydrocarbons(1)		2.5	3.1	2.7
Ethane and methane	Not specified		1.6	1.2
Sulphur, lamp test(2)	-	230	Complies	
<u>PROPERTIES</u>				
Vapour pressure at 37.8°C kPa	-	1435	N/A	N/A
Motor octane number	95	-	N/A	N/A
Corrosion (copper strip)	-	#1	Complies	
Dew point, °C	-	-25	-29	-28

Notes: (1) Butane content was 97-99% high octane isobutane:
composition exceeds minimum octane requirement

(2) Milligrams/cubic metre of vapour at 15°C and 101.325kPa

Sources: Canadian Government Specifications Board and Superior
Propane Ltd.

5. GARAGE AND SITE MODIFICATIONS

5.1 Changes Planned and Undertaken

The planning of the propane bus demonstration drew upon the current experience at OC Transpo with the fuelling, garaging and operation of a fleet of propane automobiles and small trucks operated from a garage close by the St. Laurent bus garage and upon current experience of Vienna Transit and prior experience of other properties with propane buses. The plans included the installation of facilities external to the St. Laurent garage for the storage and transfer of propane previously described.

Ontario regulations do not prohibit the parking or servicing of propane vehicles indoors, but define the conditions under which such operations can be conducted. These include:

- . the vehicle must have an installed fuel tank that is equipped with a stop fill valve (the OC Transpo propane buses have this feature incorporated)
- . the vehicle may be serviced indoors provided there are no leaks in the propane system and the tank is not filled beyond its maximum filling density (usually 80% of the internal volume)
- . the tank shut-off valve must be closed, except when propane is required for engine operation
- . the propane vehicle, while being serviced indoors, shall not be parked near a source of heat, an open flame, or any source of ignition, or near an open pit or drain.

In accordance with these requirements, changes were made in the vehicle maintenance and repair area at the St. Laurent garage to provide

the high level of safety precautions needed with propane vehicles. This was provided by the use of portable propane leak detectors, purchase of fire extinguishers suitable for minor propane fires, coupled with extensive training, sign posting, production of information on propane safety and operating procedures and supervision, and prohibition of smoking - all aimed at avoiding propane incidents.

In view of these measures, installation of extensive flame-proof lighting and heating equipment and high level ventilation systems in the bus maintenance area was considered unnecessary. It was also arranged that certain operations capable of producing sparks, such as grinding and welding, and other sources of ignition were not to be conducted within 20 feet of the propane vehicle repair area.

Despite the fact that the parking of the propane buses was acceptable under Ontario regulations, the buses were not parked inside the garage, except for tests, repairs and maintenance. The reasons for this are:

- . propane transit buses operated in Vienna, Amsterdam and previously operated in the U.S. in Chicago and San Jose, were parked outdoors, usually under cover
- . It was decided to seek a technical solution to the major sources of concern regarding indoor parking - the overfilling of the propane tanks, and the potential for subsequent leaks in the garage (see Section 7)
- . plans to build another garage on the site merited deferment of the extensive investment seen to be necessary to achieve the highest level of leak detection and ventilation.

Accordingly, the buses were parked outdoors, block heaters provided and the buses readied for service in the winter by an early

morning warm-up achieved by idling the engines. As shown later, this led to high fuel consumption in the winter months and to other inefficiencies. Operations in Vienna and trials in Stockholm offer suggestions for changes that could be made to overcome these problems in the overnight storage of buses in winter:

- . use of timed propane heaters carried in the bus to warm the cooling water before bus start-up, rather than electrical block heaters
- . hot air heating of the bus interior from an external source
- . parking of the buses under cover.

Alternatively, the technical solution to the tank overfill and potential propane leak problem should be resolved; effective instrumentation installed in the garage; and measures taken to improve the current public perception of propane safety.

6. STAFF TRAINING

6.1 Accomplishments

The awareness of propane by OC Transpo staff and their attitude to it were important to the success of the demonstration program. Internal communications and extended staff training overcame the problems that are always experienced in the introduction of new technology. The propane operations have been integrated into the total operation and staff attitudes to the alternative fuel are positive. The pool of staff experienced in the safety, conversion, fuelling, operation, maintenance and repair of alternative fuel buses and the demonstrated flexibility of the operations are an addition to the Commission's assets.

6.2 Training and Certification of Maintenance Staff

The decision to convert buses and undertake modifications within the existing maintenance shop was supported by special training, new documentation and technical support, principally provided by the engine manufacturer and technical staff from the Ministry of Transportation, Ontario. 30 members of OC Transpo staff took the S6A propane fitters' courses at Algonquin College: 29 were successful. 16 of the qualified S6A fitters undertook further courses and were awarded the S6B certificate, which enabled them to convert vehicles and certify the conversions. OC Transpo now has 18 persons on staff with the S6B qualification.

The propane engine supplier provided manuals and on-site training in the operation of the propane engine, technical service and documentation support in diagnosing and resolving engine and interfacing problems that were encountered. On-site assistance from MTO technical staff was also given frequently.

Typical documentation developed was:

- . the internal report "Rules and Procedures for the Safe Maintenance and Servicing of Propane-Powered Vehicles"
- , an installation procedures manual developed with the engine supplier
- . the propane bus safety manual
- . various reports describing equipment problems and solutions listed in Appendix 7.

The deficiencies identified in each propane and diesel bus in the demonstration fleet while in service were entered into a Road Call log. Details on repairs and inspections were recorded separately.

The supplier of the ignition and gas analysis instrumentation provided training to 8 persons at OC Transpo involved in engine set-up and optimization. Technical advice in this area was also received from: the supplier of carburetion equipment, Impco Carburetion Inc.; a U.S. vehicle conversion company and propane supplier, Petrolane Inc.; the Ontario Research Foundation; and staff at Hamilton Street Railway, who were concurrently generating information and experience in the conversion of GM diesel buses using the natural gas version of the Iveco spark-ignition engine.

6.2.1 Driver Training

All OC Transpo drivers were given instruction on steps to be taken in the event of accidents or propane leaks, but no special selection of drivers or other retraining was necessary.

6.2.2 Fuelling Staff Training

Superior Propane Ltd. personnel provided training to OC Transpo staff engaged in vehicle refuelling. The training aids provided were very similar to those used by Superior Propane in training its own staff. Although propane refuellers at retail service stations require a

provincial certificate, it was not considered necessary for OC Transpo staff to undertake a refuelling course and formal certification. Liaison and information exchange with the Ottawa Fire Department supplemented the safety training given to the OC Transpo staff.

6.2.3 Other Training

Although OC Transpo has a well-developed system for allocating and analyzing costs of maintenance and component acquisition, the system does not currently provide information on an individual bus basis related to bus availability, fuel use, kilometrage and certain other operational and maintenance details. A routine was developed for collection and analysis of selected data from the propane and diesel bus demonstration fleet. The items selected for analysis were only those which would be expected to differ between the propane and the diesel-engined fleet; data on items such as body and interior maintenance were not assembled on a bus-by-bus basis. Training was provided in the conversion of the data collected to monthly and year-to-date statistics, using the microcomputer-based demonstration data system.

7. PROPANE FLEET PERFORMANCE IN REVENUE SERVICE

7.1 Description of Service Provided

Ten buses were converted to propane, one of which was reconverted to diesel, thereby demonstrating the feasibility of conversion and reconversion. Two of the buses were converted in 1984, seven in 1985 and one in 1986.

Detailed records on the operations, maintenance activities and costs are available for the 28 month period September 1985 to 31 December 1987. The records for ten 1979 vintage GM "New Look" diesel buses operated in the same type of service are available for 1987.

In the 37 month period since the first propane bus was introduced into regular service, the propane buses have been operated for a total of 5700 days over 1,373,000 kilometers of city and suburban routes - an average of about 241 kilometers per bus-day. At the normal passenger loading level the propane buses will have provided service to about 2.5 million passengers in the OC Transpo region during the 37 months.

Since the objective of the demonstration program was to operate the propane buses under normal revenue conditions, no attempt was made to select routes for the propane fleet. Similarly, no special priority was given to the maintenance and repair of the propane buses.

7.2 Propane Bus Utilization

Buses at OC Transpo are refuelled after each day or part day in service. The number of refuelling events was counted for the propane and diesel demonstration fleet as part of the fuel economy and fuel transfer measurements. The number of refuellings in a given period can be used to compare the utilization of the buses. This is not the same as bus availability, which was not measured or considered meaningful,

since bus unavailability is based not only on the time needed to repair the bus, but also upon the highly variable period in which the bus may await repair.

Exhibit 7.1 provides a comparison of the utilization of the propane and diesel buses. During the first 10 months of 1987 when propane and diesel buses ran concurrently, the propane fleet exhibited a somewhat higher utilization level than the diesel fleet after adjustments were made for the different number of buses in each fleet (9 propane, 10 diesel for most of the year). This difference in utilization may be explained by the different ages of engines in the two fleets. The propane fleet was equipped with new engines, the diesel with older engines which may have been rebuilt from the originals supplied in 1979. (Note that diesel engines are frequently interchanged between buses and no bus has a "dedicated" diesel engine). The diesel fleet utilization, however, was negatively influenced by three major overhauls conducted on engines in 1987.

The propane fleet data shows a steady improvement in utilization rate from 1985-87 consistent with experience gained by OC Transpo staff in the set-up and maintenance of the propane engines.

Surprisingly, the utilization rate did not vary significantly with the season. The winter cold start problems identified in the early months of the demonstration were overcome by a winter early morning engine warm-up procedure. Higher demand for buses in the winter may also have contributed to the winter utilization measurement. Variation in utilization rate between individual buses in the fleets in 1987 ranged from a low of 63% to a high of 96% for the diesel bus and from a low of 38% to a high of 100% in the propane fleet. The data does not provide information on the long-term propane bus utilization rate and engine durability, but does show that service factors comparable to those of diesel buses can be achieved under appropriate vehicle conversion and maintenance conditions.

Exhibit 7.1
Comparative Bus Utilization

	<u>% Possible(1)</u>	<u>Propane as % Diesel(2)</u>
Diesel Fleet 1987 (10 months)	85	-
Propane " " " "	93	109
Propane Fleet 1986 (12 months)	79	93
Propane " 1985 (last 4 months)	75	88

Notes: (1) Taken as 260 days' utilization per year (5 days/week, 52 weeks/year)

(2) Using 1987 diesel data as the base

7.3 Distance Travelled

Each bus in the demonstration was equipped with a hubometer which was read at every refuelling to provide data on total kilometers travelled, kilometers per fill (or operating day) and fuel economy (litres/100km).

The most pertinent facts concerning distance travelled are summarized in Exhibits 7.2 and 7.3 and the following, which shows the total distance travelled by the propane fleet in 37 months:

1984 negligible

1985 374,795km

1986 495,214km

1987 503,050km

Total rounded 1,373,000km

or about 4000km/bus/month in revenue service.

Exhibit 7.2
Bus Distance Travelled In Revenue Service

	km/year <u>x1000</u>	# days <u>in service</u>	km/day <u>fleet average</u>
<u>PROPANE BUS FLEET</u>			
1984	-	negligible	-
1985	374.8	1420 (1)	264
1986	495.2	2052	242
1987	<u>503.1</u>	<u>2245</u>	<u>224</u>
Total 37 months	1,373.1	5717	240
<u>DIESEL BUS FLEET</u>			
1987	587.1	2138	275

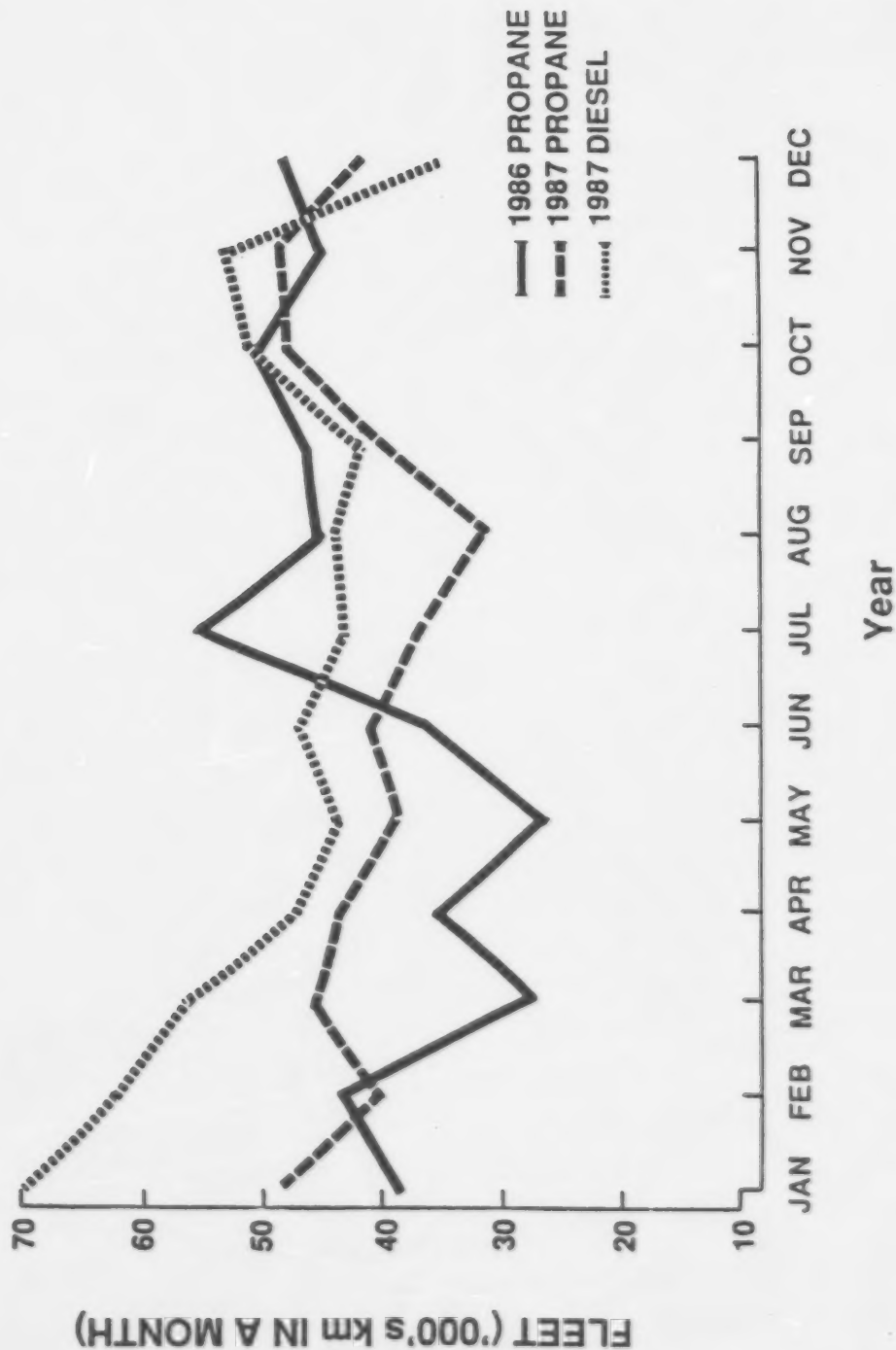
Note (1) Estimated from 4 month data

In 1987 the buses in the propane fleet averaged 4190km/month/bus and 224km/operating day. In the same period, the 10 buses in the diesel fleet averaged 4890km/bus/month and 275km/operating day (see Exhibit 7.3). The difference in the km/day between the propane and diesel fleets (see Exhibit 7.2) most probably reflects an unplanned bias in the selection of propane buses for downtown city routes and diesel buses for the longer suburban routes. This is consistent with the wider variation in km/day values reported among the buses in the diesel fleet than for the propane buses in the same period.

The maximum km/fill reported for any propane bus over the 37 month period was 495km. This should be compared with the 700km/fill requirement of the propane bus specification.

Exhibit 7.3

FLEET MILEAGE



The propane fleet average km/day (or fill) ranged from a high of 298 in September 1985 to 216 in May 1987 and January 1987. No seasonal pattern was discerned in the propane fleet monthly kilometers travelled. The average km/day showed a slight trend to lower values over the period 1985 to 31 December 1987: the reason is not apparent.

7.4 Bus Reliability in Service

The frequency of vehicle road calls (reports of deficiencies prepared by bus drivers) is one measure of in-service reliability of buses in the demonstration fleets. A comparison of road calls for propane and diesel buses is as follows:

- i. Vehicle Road Call Reports (see Appendix 8 and Exhibit 7.4) for 1987 show that the propane buses generated 2.7 times the level of reported deficiencies of the diesel bus demonstration fleet - 134 propane bus deficiencies compared to 49 diesel bus deficiencies. The propane deficiencies/bus-month were 1.3 compared to 0.5/bus-month in the diesel fleet.
- ii. The frequency of propane road calls decreased slowly over time during the demonstration.
- iii. The road calls in the propane fleet over the entire demonstration period averaged 1.4 calls/bus-month.
- iv. About 77% of the propane road calls were attributed to deficiencies in the propane engine, propane system accessories within the bus, interfacing of the new engine with the GM bus and the properties of propane.
- v. About 11% of propane bus calls in the demonstration period had an undefined source, i.e. no source of the problems was found at the garage.

Exhibit 7.4
Bus Road Call Frequency

	<u># Buses</u>	<u># Calls</u>	<u># Related to Engine/Fuel System</u>
<u>PROPANE BUSES</u>			
1984	2	4	4
1985	9	103	92
1986	10	174	115
1987 (10 months)	9	143	86
<u>DIESEL BUSES</u>			
1987 (10 months)	10	59	15

vi. The 5 most frequent sources of calls for propane buses (see ranking in Exhibit 7.5) were:

No power	19%
Engine stalled	15%
Stiff steering	5%
Hot engine	3.5%
Acceleration	3.5%

vii. The most serious call item was a minor oil fire in the engine compartment of one propane bus.

viii. Propane buses ran out of fuel on 3 occasions in the demonstration period.

ix. The odour of propane was cited in 2.5% of the calls (11 calls in total). However, odour was also cited among the diesel bus problems: 2 calls, 4% of diesel vehicle calls.

Exhibit 7.5

Analysis of Bus Road Calls

	<u>Rank</u>	<u># Calls</u>
<u>PROPANE BUSES</u>		
No power	1	81
Engine stalled	2	65
Stiff steering	3	22
Hot engine	4	15
Acceleration	4	15
Brakes	6	14
Backfiring	7	12
No start	8	11
Smell of propane	8	11
Vibration	8	11
Rough engine	11	7
Noisy muffler	11	7
Engine misses on take-off	13	6
Water leak	13	6
Coolant leak	15	5
Oil leak	15	5
Air pressure loss	15	5
High idle engine speed	15	5

Others: Transmission, low power, low coolant, hard start, broken belts, propane leak (3), out of fuel (3), engine fire, frozen propane valve, blown head gasket, steam from engine.

DIESEL BUSES 10 month data

Brakes	1	7
No start	2	6
Battery	2	6
Hot engine	4	4
Front end shimmy	4	4
Smell in bus	6	2

Others: Noise in rear, defective alternator, no power, engine misses

- x. The road calls on propane buses which one would expect to be cold-weather related (engine stalls, no start, no power or low power) were not higher in the winter than in the summer months. They were almost evenly distributed over each quarter of the year.
- xi. The frequency of road calls was fairly consistent between propane buses over the demonstration period, if one poor performing bus in each year 1985 and 1987 is omitted. In 1987, for example, one bus in the fleet of 9 in service accounted for 27% of the road calls; in 1986, another for 16% (when 10 propane buses were in service).

The steps taken to remedy the defects reported in the road calls are described in Appendix 8.

7.5 Summary of Major Propane Engine-Related Challenges and Solutions

The propane engines used in the demonstration were essentially prototypes. The performance was further influenced by the novelty of coupling these engines to the Allison transmission and the small volume of the engine compartment. At the outset of the demonstration OC Transpo had limited experience and equipment with which to address the numerous challenges which arose. The major challenges and solutions are discussed next in a logical order rather than in the chronological order in which the challenges were met.

7.5.1 Engine Optimization

The propane engines were delivered with a factory set (but adjustable) power setting. The ignition timing was set at given engine speeds with the bus on the OC Transpo chassis dynamometer. After operating in service for some time, each bus needed to be retuned, but it was not until an Allen "Smart-scope" (exhaust gas analyzer and ignition timing instrumentation) was installed that a consistent method for setting the air-fuel ratio and ignition timing was achieved.

In the period before the effect of the somewhat erratic engine set-up process was recognized, each engine had a unique and different level of settings from other engines in the demonstration. In retrospect, a number of the problems encountered initially can be traced in part to the thermal stress which arose from high engine and engine exhaust temperatures brought on by the combustion of a propane-rich fuel-air mixture, due to inappropriate settings.

7.5.2 Engine Knock

Although propane has a high octane number and therefore a high resistance to premature ignition ("knocking") compared to gasoline, propane engines can be caused to knock by variations in the quality of the fuel, excessive cylinder compression ratios, high air-fuel and engine temperatures. Two, and possibly three, incidents of engine damage in the demonstration may be attributed to engine knock, which was traced to excessively high air inlet temperatures and temperature build-up in the engine and engine compartment. The solution found was to insulate the air intake system from the heat of the engine, and to modify the fuel combustion conditions by operating at a leaner air-to-fuel ratio.

It has been recommended that the possibility of engine knock be further reduced by changing the compression ratio. One engine was modified and is operating at a compression ratio of 9.5:1, although 10:1 is now considered to be the optimum.

7.5.3 Engine Overspeeding

The engine governor used to limit the maximum speed of the propane engine is of the mechanical vacuum-activated type. Wear of bearings in the governor and deterioration of the synthetic rubber vacuum hose (probably due to thermal stress) led to vacuum loss, failure of the governor, engine over-revving to the point of damage to two propane

engines. Modifications were made to the existing governor systems and an overspeed ignition cut-off device (Limitron maximum speed governor) installed in each bus, which prevents damage due to over-revving. However, the service life of the Limitron governor has yet to be determined. One bus was equipped with a Sturdy electronic governor.

7.5.4 Minor Fires

Four minor fires occurred in the engine compartments of the propane buses. Three occurred in the garage, were rapidly noticed and extinguished without injury or damage to the bus or garage property. The fourth fire occurred when an empty bus was returning to the garage, but was rapidly put out by the driver using the fire extinguisher carried on the bus. This incident resulted in a road call and, as a precaution, the Ottawa Fire Department was called to the scene.

The source of these fires was traced to oil which leaked from the blow-by unit of the crankcase on to the hot exhaust manifold and then ignited. The leak was presumably due to propane accumulation in the crankcase oil and leakage through an unsealed cap on the crankcase ventilation box. All caps were sealed, since when no fires have occurred. In future propane engine designs it may be appropriate to add positive crankcase ventilation.

7.5.5 Ignition System Failures

The high engine temperatures associated with the set-up of the engines at the beginning of the demonstration period noted in Section 7.5.2 caused thermal stress to a number of components. The spark-plug caps supplied were made of a phenolic resin which became embrittled in the high temperature environment and required frequent replacement. Lower temperatures now maintained in the engine compartment and shielding the phenolic caps with silicone rubber covers have eliminated this problem.

The spark-plug life at 15,000km is substantially lower than the 25,000km replacement level suggested by the engine supplier and the life has not changed significantly over the demonstration period.

The unsatisfactory starting and stalling record of the propane engines noted in the road call reports places stress on the starters: the high replacement rate (average 45,000km) for this component of the electrical system has persisted throughout the demonstration period.

7.5.6 Poor Cold Start

The propane engines have an unsatisfactory cold-start record in all seasons and this may be due in part to the anomaly that the vapourizer is designed to draw heat from the water coolant system whose primary purpose is to cool the engine. When the propane engine is started up the cold vapourizer is further cooled by the vapourizing of liquid propane before the engine heat output warms the coolant. This leads to the induction of unvapourized liquid propane into the engine and an air-fuel mixture which is too rich to be ignited. The engine may therefore start, run briefly and stall. The heat balance in the coolant/vapourizer system needs to be optimized.

The engine cold-start performance in winter was further reduced by the decision not to garage the buses indoors overnight. Outdoor storage was improved by the installation of block heaters. However, in winter and summer other factors in the carburetion and electrical systems continue to contribute to an unsatisfactory vehicle start performance. Better mixture formation and air-fuel ratio control under all and part load conditions are required. More recent carburetion system designs may provide a solution. It may be noted that diesel bus engines subjected to a similar cold soak require the installation of a block heater to ensure prompt starting capability.

7.5.7 Filter Contamination

A period was experienced late in 1985 when the propane filters needed frequent replacement, which was traced to build-up of a black magnetic solid in the filter of the filter/fuel lock assembly. At the same time, it was noted that an oily substance was accumulating in the vapourizers. It was suspected that the black solid originated with scale in the bulk storage tank, and the oily substance to oil contamination in the fuel or the production of a polymer in the vapourizer from components other than propane in the fuel. The orientation of the vapourizer allowed the oily substance to accumulate. Both problems diminished in 1986, but the necessity for frequent filter replacement returned in 1987.

7.5.8 Engine Coolant Problems

The complexity of the engine coolant system led to losses of coolant, subsequent engine overheating and some failures. Coolant loss was also attributed to an inadequate design modification used in converting the diesel engine heads to accept the spark-plug assembly.

7.6 Fuel Economy

7.6.1 Overview of Fuel Economy

The cost of propane bus operations, the range of the buses and the logistical support required for fuel storage and refuelling are dependent on the fuel consumption of the bus. Diesel has the advantage that its energy content per litre is 1.5 times that of propane. The compression ignition engine used with diesel fuel is significantly more efficient than the spark-ignition engine used with propane. The outcome is a large volumetric efficiency advantage for diesel fuel. In the controlled track test the ratio of propane to diesel consumption by volume was 1.7:1. This comparative level was not sustained in bus

operation throughout the demonstration period: a level of 2:1 was reached. As discussed below, this includes propane consumed in operating the propane buses for extended periods at idle in the winter mornings while the diesel fleet (garaged indoors overnight) did not incur this fuel penalty.

Fuel consumption measured in the period 1 May to 31 October 1987 showed a propane-to-diesel fuel consumption ratio (by volume) of 1.9:1. During this time the propane buses had a fuel economy of 98 litres/100km and the diesel buses 51.6 litres/100km. In contrast, the ratio in the period November to April was 2.18:1. As shown in Exhibit 7.6, the propane buses had higher fuel efficiency throughout 1985 and 1986 than in 1987.

Exhibit 7.6
Comparative Bus Fuel Consumption

	Fleet Average Fuel Consumption litres/100km		
	<u>PROPANE</u>	<u>DIESEL</u>	<u>RATIO PROPANE:DIESEL</u>
1987	110	53.4	2.06
1986	108.1	N/A	N/A
1985	97.1	"	"
1985-87	105.6	"	"

The fuel economy for the propane buses over the almost 1.4 million kilometers of measured revenue service averaged 105.6 litres/100km. Further detail of the fuel economy of the propane and diesel fleets is contained in Exhibit 7.7.

Exhibit 7.7

Fuel Data from Demonstration

OC TRANSPO PUMPAGE FLEET FUEL DATA 1987

	FLEET No	FUEL ACCOUNT 1/1000s	FUEL ADDED Litres	# FILLS	AVG FILL Litres	FUEL DELIVERED TO SITE	KN/MS /FILL
JANUARY	40730	127	61967	216	287	60551	226
FEBRUARY	40726	123	49349	169	292	50950	230
MARCH	43507	116	53325	192	278	54550	240
APRIL	43599	105	45571	104	240	41900	237
MAY	30624	96	36096	179	206	30916	216
JUNE	40750	95	30017	102	213	35070	224
JULY	36201	91	32946	173	190	30661	210
AUGUST	31559	102	31590	165	194	29650	190
SEPTEMBER	39600	100	39640	187	212	33700	212
OCTOBER	47004	101	48312	194	249	57793	246
NOVEMBER	40443	100	40301	212	220	40301	229
DECEMBER	41601	155	64697	192	337	64697	217
TOTAL 1987	503050	110	551192	2245	246	555539	224
"WINTER" (NOV-APR)	260644	120	323210	1165	277	320949	231
"SUMMER" (MAY-OCT)	234306	90	705422	1080	212	234590	217

OC TRANSPO DIESEL FLEET FUEL DATA 1987

	FLEET No	FUEL ACCOUNT 1/1000s	FUEL ADDED Litres	# FILLS	AVG FILL Litres	FUEL DELIVERED TO SITE	KN/MS /FILL
JANUARY	63056	51.61	32953	226	146	N/A	203
FEBRUARY	62042	57.91	36394	235	155	N/A	267
MARCH	56540	58.26	32941	249	132	N/A	227
APRIL	47002	55.37	26060	209	125	N/A	235
MAY	43428	55.25	23995	193	124	N/A	225
JUNE	46942	52.04	24430	160	145	N/A	219
JULY	62056	51.70	22137	121	103	N/A	354
AUGUST	43706	50.14	21914	70	171	N/A	341
SEPTEMBER	41459	50.03	21075	149	141	N/A	278
OCTOBER	51256	49.81	25532	161	159	N/A	318
NOVEMBER	52449	52.40	27527	154	179	N/A	341
DECEMBER	34724	53.92	10722	145	129	N/A	239
TOTAL 1987	507140	53.43	313700	2130	147	N/A	275
"WINTER" (NOV-APR)	317493	54.99	174605	1210	143	N/A	261
"SUMMER" (MAY-OCT)	209647	51.59	139103	920	151	N/A	293

Exhibit 7.7 continued

OC TRANSPO PROPANE FLEET FUEL DATA 1966

	FLEET to	FUEL ECONOMY \$/1000m	FUEL ADDED litres	# PILLS	AVG FILL litres	FUEL DELIVERED TO SITE	CM/AUS /PILL
JANUARY	38933	138.76	54814	188	300	57125	216
FEBRUARY	43485	128.24	55764	172	324	57836	253
MARCH	27883	135.79	36775	124	297	33651	218
APRIL	35763	112.14	40037	149	269	65658	240
MAY	25373	102.21	25936	106	245	20793	239
JUNE	36541	91.83	33262	155	215	31878	236
JULY	55361	87.54	48464	210	231	49878	284
AUGUST	44153	86.17	38047	170	224	35551	240
SEPTEMBER	45811	97.27	44559	191	223	50102	240
OCTOBER	50147	104.44	52372	209	251	47180	240
NOVEMBER	44749	115.06	53276	195	273	54383	229
DECEMBER	47875	110.66	52977	191	277	54585	251
TOTAL 1966	495214	106.13	535401	2052	261	538420	241
"WINTER" (NOV-APR)	237828	123.13	292863	1011	296	303038	235
"SUMMER" (MAY-OCT)	257386	94.27	242538	1041	233	235382	247

OC TRANSPO PROPANE FLEET FUEL DATA 1965

	FLEET to	FUEL ECONOMY \$/1000m	FUEL ADDED litres	# PILLS	AVG FILL litres	FUEL DELIVERED TO SITE	CM/AUS /PILL
JANUARY	6118	120.99	7402				
FEBRUARY	21388	96.19	19283				
MARCH	25855	85.78	22128				
APRIL	10299	116.90	21407				
MAY	24084	109.53	27167				
JUNE	24878	75.72	20347				
JULY	31796	70.02	22263				
AUGUST	47149	80.70	38886				
SEPTEMBER	47089	92.72	43661	158	276	47615	298
OCTOBER	56583	101.87	51449	187	275	51227	270
NOVEMBER	41895	113.81	14772	160	292	49325	237
DECEMBER	33837	129.93	63963	149	295	44887	227
TOTAL 1965	374795	97.11	363978				
"WINTER" (NOV-APR)	146584	109.84	161085				
"SUMMER" (MAY-OCT)	228211	88.94	202973				

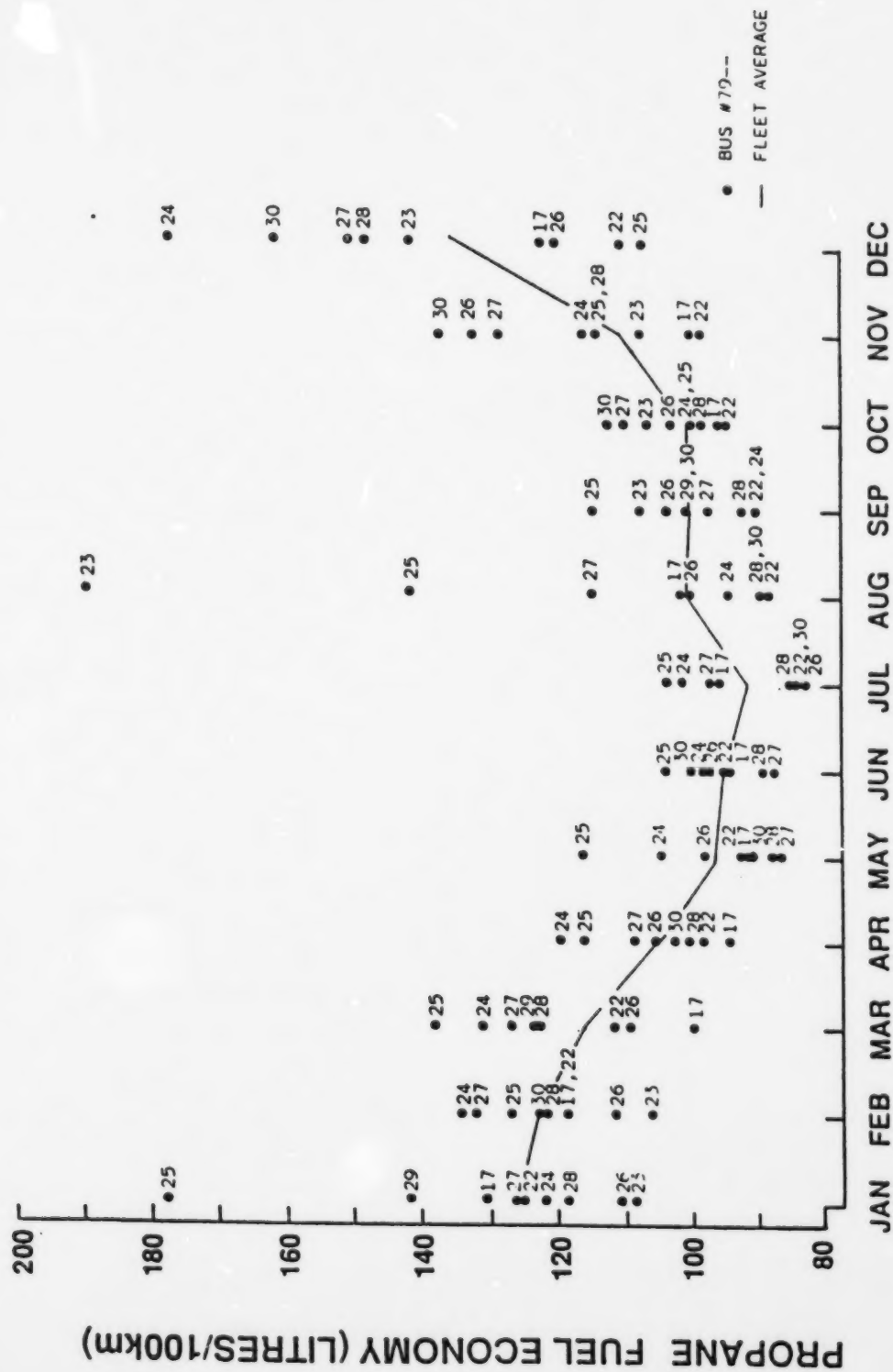
7.6.2 Fuel Economy Variability

Exhibit 7.8 illustrates the seasonal variability in the fuel economy of the propane fleet, due in major part to variations in the propane warm-up period. However, as shown in Exhibit 7.9, fuel consumption also increased in the diesel buses in the winter period, but not to the same extent. The wide variation in fuel economy between individual buses in both the propane and diesel fleets is noteworthy, as are the changes in fuel economy in each bus over time. Since the fuel economy spread among the diesel buses measured in 1987 was frequently greater than that among the propane buses, it may be concluded that the engine tune-up and maintenance process used for the propane fleet is no less effective than that for the diesel fleet.

7.6.3 Bus Range Considerations

Exhibit 7.7 also summarizes fleet data on the frequency of refuelling and the average volume of fuel delivered daily to the propane and diesel buses in the demonstration. On average, in 1987 the propane buses received 246 litres per fill and this was used to travel an average of 224 kilometers. Because of the higher energy content, the diesel fuel volume per fill during the same period was lower at an average of 147 litres per fill.

The bus-to-bus variation in the volume of propane consumed varied widely according to the mileage and to a lesser extent to the fuel efficiency of the propane bus. Examination of the refuelling history of the propane fleet showed that only 1.5% of the fills measured exceeded 400 litres. Only 0.1% of the fills (6 cases) required propane addition exceeding 500 litres; these were made after bus repair at the garage. The maximum fill volume recorded was 613 litres.



1987



NOTE: MARCH, APRIL AND MAY READINGS FOR BUS #7904 ARE NOT REPRESENTED; READINGS ARE OFF SCALE.

The 800 litre (internal volume) propane storage tank with a controlled 80% fill level to 640 litres therefore appears adequate, despite the fact that the propane buses were not segregated for short-run service. Of the more than 5000 bus-days of operation, the propane buses "ran out of fuel" in revenue service on only 3 occasions.

However, the refuelling of diesel buses shows a wider variability in fuel volume per fill than experienced with propane. Thus 7.3% of the diesel bus refuellings in 1987 were above 250 litres of diesel fuel (equivalent to almost 500 litres of propane) and 2.6% above the 350 litre level. This would provide a diesel bus range in excess of that available from a typical propane bus equipped with an 800 litre water capacity (640 litre propane capacity) fuel tank. The diesel fuel fill volumes support the rationale for the 700km range target originally set for the propane buses.

7.6.4 Effect of Pollution Control on Fuel Economy and Engine Capability

The naturally aspirated spark-ignition engines in the OC Transpo propane bus fleet are operated at an air-fuel ratio close to that which would be optimum for use of a three-way catalyst for control of nitrogen oxide, carbon monoxide and unburned hydrocarbon at the 1991 EPA levels. By analogy with the systems used with methanol and from preliminary data on pollution-controlled propane engines, no significant deterioration of the fuel economy is expected with use of the 3-way catalyst system, compared to the results from the demonstration fleet. There is the possibility that lean-burn technology applied to a turbo-charged spark-ignition propane engine could meet the 1991 EPA requirements with a fuel economy significantly better than that currently demonstrated.

The prospect for diesel engines is less attractive. The principal pollutant requiring control in these engines is particulates and various regenerative particulate trap technologies are being tested. Some of

those involved in this development have provided information on their systems and expectations, the consensus of which is that the trap technology most likely to be introduced for buses in the 1991-95 period will result in a 6% increase in fuel consumption, together with a requirement for diesel buses to return to the garage for trap regeneration. A longer-term development in diesel trap technology has the potential for reducing the diesel fuel penalty to 4%. In either case, the effect will be to reduce the competitiveness of the diesel engine compared to those engines (such as those fuelled by propane, natural gas or methanol) which can readily meet the 1991 particulate requirement without use of traps.

The fuel consumption penalty for particulate control in diesel will be aggravated by the requirement of trap technology for a higher quality diesel fuel than that currently used. The maintenance of trapped diesel engines will be more complex and expensive than the current technology diesel engines. These factors are considered in the comparative economics for future bus operations discussed in Section 9.

Legislation on bus and truck particulate and gaseous emissions is paralleled by legislation and social pressure to reduce the noise level of urban vehicles. The inherently low noise of the spark-ignition engine compared to the compression ignition (diesel) engine has been shown in the propane bus demonstration. The propane engine will therefore be easier to adapt to emerging noise legislation than the diesel engine and may have a further impact on the relative cost of propane and diesel bus acquisition, operation and maintenance.

7.7 Compression Ratio Change

The compression ratio of one engine was reduced and the fuel consumption measured for one year. The fuel consumption of this bus was 2.5% higher per kilometer than the fleet average, but this is well within the spread of engines with comparable compression ratios and

cannot be used to confirm the expected degradation in fuel economy. The fuel consumption of the low compression-engined bus before the change was high and affected by other factors. The piston change was made when this bus was being repaired.

7.8 Maintenance of the Demonstration Buses

Maintenance activities and costs of the propane fleet in 1987 were compared with those for the 10 diesel buses. The comparison is based on data related to the fuel/engine and drive-train components, it being assumed that the common elements, such as body and interior maintenance, would not differ between the propane and diesel buses.

The findings are:

- . Mechanics' labour requirement for a propane bus was about 4.5 times that of a diesel bus.
- . Propane buses were checked on the dynamometer twice as frequently as diesel buses. This is consistent with the finding that the frequency of repair and requirement for engine tune-up was higher in the propane fleet than in the diesel.
- . Average total cost of maintenance and repair of a propane bus was about 1.6 times that of the diesel. However, the diesel engines were "old" engines, the propane new in 1984. Excluding the repair (rebuild) cost attributed to the age of the diesel engines, the total maintenance and repair costs of the average propane bus are estimated to be about twice that of the comparable diesel bus, see Section 9.
- . Annualized mechanics' labour requirement for the propane fleet increased in 1986 and was reduced in 1987. This reduction may be due in part to a shortage of maintenance staff causing deferred

maintenance and in part to improved efficiency gained through experience:

Annualized Mechanics' Labour (hours/bus converted)		Increase/Decrease Over Previous Year
1985	240	
1986	286	19%
1987	205	(28%)

- Annualized average cost of propane bus maintenance and repair increased steadily over the three years at a rate in excess of cost inflation:

Annualized Average Maintenance Cost (\$/bus in service)		Increase Over Previous Year
1985	6020	
1986	7780	30%
1987	8600	10.5%

- Maintenance and repair costs/100km of revenue service (see Exhibit 7.10) were highest in the winter months and remained at about the same level of \$14-15/100km in 1986 and 1987. The diesel bus maintenance cost/100km was at the \$8/100km level in 1987.
- Measured operating and maintenance costs in 1987 indicate a 7¢/km advantage for the diesel bus, entirely due to the lower maintenance costs incurred by the diesel fleet in the period:

		Buses	
		Propane	Diesel
Measured total cost	\$/100km	39.75	32.58
Measured maintenance cost	\$/100km	15.43	8.36
Maintenance as % total measured costs		38.8	25.6

Exhibit 7.10

Maintenance Costs In Demonstration Period

GC TRAINING PROGRAM FLEET MAINTENANCE AND TOTAL COSTS 1967

FLEET	MAINTENANCE	TOTAL	MAINT COST	TOTAL COST
IN	\$	\$/1000	/HRS DAY	/HRS DAY
JANUARY	68730	16697	21.95	49.52
FEBRUARY	40226	16489	48.99	67.28
MARCH	65807	4750	16.35	33.49
APRIL	63599	9930	22.79	46.85
MAY	30624	2803	7.26	20.44
JUNE	48750	6181	18.26	32.90
JULY	36281	1336	3.48	22.41
AUGUST	31359	3550	11.32	21.52
SEPTEMBER	39600	4917	12.39	22.73
OCTOBER	47684	5836	12.23	48.45
NOVEMBER	48443	3932	8.12	31.39
DECEMBER	41681	9177	22.82	49.80
TOTAL 1967	583850	77611	15.43	39.75
"WINTER"	266664	54990	20.47	45.40
(NOV-APR)				
"SUMMER"	236206	22621	9.65	33.10
(MAY-OCT)				

GC TRAINING PROGRAM FLEET MAINTENANCE AND TOTAL COSTS 1966

FLEET	MAINTENANCE	TOTAL	MAINT COST	TOTAL COST
IN	\$	\$/1000	/HRS DAY	/HRS DAY
JANUARY	38933	7247	18.61	51.32
FEBRUARY	43485	18121	23.27	56.93
MARCH	27803	7569	27.95	64.61
APRIL	35703	5947	16.44	38.73
MAY	25373	5133	20.23	48.55
JUNE	36561	6654	17.44	48.79
JULY	55361	6780	12.10	32.79
AUGUST	44153	2316	5.25	22.51
SEPTEMBER	45811	5867	12.81	34.85
OCTOBER	50147	3897	6.18	38.62
NOVEMBER	44749	6286	14.85	43.05
DECEMBER	41875	3747	7.83	29.82
TOTAL 1966	495214	70404	14.23	39.84
"WINTER"	237820	48917	17.70	45.72
(NOV-APR)				
"SUMMER"	257384	29567	11.49	32.87
(MAY-OCT)				

Exhibit 7.10 continued

Maintenance Costs In Demonstration Period

MC TRANSPO PROPANE FLEET MAINTENANCE AND TOTAL COSTS 1985

FLEET	MAINTENANCE	TOTAL	MAINT COST	TOTAL COST		
to	\$	\$/1000h	/HRS DAY	/HRS DAY		
SEPTEMBER	41049	3414	7.25	31.49	21.41	94.45
OCTOBER	50543	4495	8.90	32.36	24.04	87.40
NOVEMBER	61095	4146	10.09	36.10	25.91	92.72
DECEMBER	11437	5543	16.30	54.00	37.20	122.81
SEPT-DEC	175524	17590	10.20	8.00	8.00	888

MC TRANSPO DIESEL FLEET MAINTENANCE AND TOTAL COSTS 1987

FLEET	MAINTENANCE	TOTAL	MAINT COST	TOTAL COST		
to	\$	\$/1000h	/HRS DAY	/HRS DAY		
JANUARY	63956	4827	9.44	30.44	26.67	86.00
FEBRUARY	62842	482	1.09	20.54	2.90	65.63
MARCH	56540	16623	29.40	52.16	66.76	120.72
APRIL	47082	6105	12.97	27.00	19.21	81.35
MAY	61428	845	1.95	27.40	4.30	62.28
JUNE	46942	2126	4.53	34.19	12.65	95.52
JULY	62056	2759	6.39	27.27	22.64	96.40
AUGUST	43706	3891	8.90	30.23	30.40	110.54
SEPTEMBER	61659	3240	7.84	31.76	21.01	88.37
OCTOBER	51256	6222	8.26	31.05	26.22	96.05
NOVEMBER	52449	371	0.71	29.00	2.41	85.42
DECEMBER	14724	2279	6.42	29.49	15.37	70.41
TOTAL 1987	587140	49109	8.36	32.50	22.97	89.47
"WINTER" (NOV-APR)	317493	22037	10.09	33.30	26.30	86.01
"SUMMER" (MAY-OCT)	269647	17072	6.33	31.73	18.56	92.99

- Propane bus maintenance costs in 1986 were a similar proportion of the total cost, but higher than in 1985:

Maintenance as % Total Measured Cost/100km

<u>In Propane Fleet</u>	
1987	38.8%
1986	37.7%
1985 (4 months)	27.4%

7.9 Driver and Rider Survey

7.9.1 Driver Response

Call reports from drivers provided their opinions on propane buses and were supplemented by interviews. In view of the clarity of the information collected in this way, it was considered unnecessary to implement a detailed driver and rider survey.

The principal concerns with propane reported by drivers were:

- I. Buses converted had manual steering. The propane buses were reported to have "stiff steering", due to the added weight of the propane tank assembly behind the front axle.
- II. Odour of propane. This is due to the stenching agent added to propane for leak detection purposes and the location of the exhaust at the lower rear of the bus. The exhaust in diesel buses is at the rear top. Note that odour was also reported, but less frequently, in the diesel test fleet.
- III. Inability to start the bus was a reported nuisance.

The advantages reported by drivers were:

- i. Low noise level within the propane bus.
- ii. Reduced vibration compared to diesel.
- iii. Excellent bus pull-away from stops, due to the high engine torque at low speed, characteristic of the propane engine.

Drivers are indifferent to whether they are assigned a propane or a diesel bus. They have no concerns about safety.

7.9.2 Rider Response

In spite of the signs on the propane buses, the vast majority of riders appear to be unaware that they are riding a bus which differs in any way from the standard diesel bus. When prompted, they are able to recognize the reduced noise and vibration level, but attach little importance to these attributes. No complaints or commendations were registered by the public that can be attributed to use of propane. Driver and rider indifference to the changes in the bus and fuel indicate that there is unlikely to be a negative reaction to further expansion of propane use.

7.10 Factors Which Could Improve the Performance of Propane Buses

7.10.1 Status

Experience accumulated to date with the propane fleet has been positive: the many obstacles that exist to the introduction of new technologies have been overcome and the propane buses have been absorbed within the system. The limitations of the prototype engines, the present test equipment and operational procedures have been recognized and the means to overcome them defined. If the improvements could be adopted, there is no doubt that the reliability, performance and operational economy of propane buses could reach and exceed the current

diesel bus standards. Particularly outstanding performance can be expected from the next generation of propane buses, especially in the areas of pollution control and ride quality.

The means to overcome the current barriers to expanded use of propane in transit buses include:

- i. Series production of warranted dedicated propane engines designed for use in transit buses.
- ii. Technical improvements to the bus (see Exhibit 7.11).
- iii. Technical improvements to the propane engine.
- iv. Improved operating costs through implementation of items 1-3 and lower costs for propane relative to diesel fuel than those achieved in the demonstration.

7.10.2 Series Production of Engines

The Iveco engine (diesel) modified for propane use in the GM bus with reverse rotation coupled to the Allison V730 transmission is difficult to service because some of the service points do not face the rear of the bus and access through the removal of the rear seat is limited.

The carburetion equipment commercially available to the engine manufacturer in 1982-3 has now been superseded and modern propane carburetion and fuel control would improve the performance and reliability of the propane engine. One bus equipped with an Impco 2000 mixer and a Sturdy electronic fuel supply governing system indicates that a substantial improvement in reliability may be achieved. Further testing is required.

Exhibit 7.11
Defined Propane Engine Improvements

	<u>STATUS/REQUIREMENT</u>	<u>IMPROVEMENT</u>
ENGINE INSTALLATION	Improve accessibility to alternator, starter motor, mixer ignition coil	Design for access. Omit rebuild for reverse rotation; change transmission
FUEL (CARBURETION) SYSTEM	Improve reliability, durability Improve cold startability Replace mechanical governor	Heavy duty system required Preheated converter, improved idle mixture adjustment Electronic governor/max.speed governor Electronic feedback from exhaust gas sensor/rpm
IGNITION SYSTEM	Improve analytical (set equipment and procedure) Improve spark-plug life	Electronic map-control of ignition timing; max. engine speed governor; heat resistant components 25,000km life
COMBUSTION SYSTEM	Reduce potential for engine knock Reduce emissions	10:1 CR for fuel flexibility in naturally aspirated engine; knock sensor and electronic ignition control Design for high turbulence and swirl Long term - lean mixture with electronic control
ENGINE PERFORMANCE	Satisfactory Excellent drive-off torque and speed/power	Increase max hp to 210 for future accessories Allows for simplified gear box
ENGINE EMISSIONS	High NOx and low particulate level	Use fuel management system with electronic ignition timing, exhaust gas and air-fuel ratio feedback, 3-way catalyst
ENGINE MAINTENANCE	Simplify, reduce frequency	More robust design; improved alternator

It may be possible to equip new buses or refit existing buses with a total drive train - a factory-integrated propane engine and transmission system - and thereby overcome the engine compartment size limitation and the need to alter the rotation of the engine, which limits the performance of the engine, may affect durability and certainly affects the cost.

7.10.3 Bus Changes

Easier steering of the propane bus can be achieved by the addition of power-assisted steering. This has been used by Hamilton Street Railway to improve the steering of natural gas buses.

The odour of propane in the bus exhaust can be reduced by avoidance of unburnt propane. Even with the present configuration the odour level can be reduced by relocation of the exhaust pipe to provide a conventional above-bus vertical discharge.

It may be advantageous to further increase the range of the propane bus by use of an additional propane tank: the space usually occupied by the diesel tank was not utilized in the present conversions.

7.10.4 Engine Changes

The engine manufacturer (Dereco), together with staff of OC Transpo and MTO, has defined changes needed for improved performance, pollution control and component reliability, as summarized in Exhibit 7.11.

7.10.5 Other Changes

Indoor storage of the propane buses in winter would solve a number of the cold-start problems. The principal problem is that buses may be overfilled with cold propane and then brought into the warm garage when

the thermal expansion of the propane would cause liquid propane to be vented through the relief valve and be ignited by a flame or spark source within the garage. A proposed solution used occasionally in Europe in the past in small vehicles is to add an appropriately valved empty tank to contain the expansion. A design concept for bus use of an "overspill" tank was developed by OC Transpo and MTO. Hovey Industries Ltd. of Ottawa investigated its practical feasibility. The essential transfer valve required to implement the concept was unavailable and it is by no means certain that this technical solution would be accepted by the transit community.

The improvements in propane fuel economy available through use of lean-burn turbocharged engines and future cost increases in diesel fuel could reduce the cost of propane bus operations relative to diesel.

8. OPERATION OF FUEL STORAGE AND REFUELLING FACILITIES

1.45 million litres of propane were delivered to the two-tank storage facility in the period January 1985 to 31 December 1987. Separate records of deliveries to site and of fuel dispensed to buses are maintained. From these records it would appear that propane losses in the amount of 0.8-1% of the delivered volumes were incurred in transfer operations and the venting of bus fuel tanks before vehicle repair.

The peak throughput of the storage facility was 60,550 litres/month (5 times the maximum capacity of the storage tanks); the average throughput in 1987 was 46,000 litres/month. 2-3 road tanker deliveries per week maintained the required level of storage inventory.

No major spills of propane, fires, or injuries occurred at the bulk storage and dispensing facility. The dispenser pump motors required service in three instances, but this is within the anticipated mean time between failure frequency.

Detailed records were maintained of the refuelling operation. The average fill in 1987 was 246 litres and the average price of propane per litre was 18.4¢. The refuelling was routinely accomplished in less than 4 minutes (the same as for a diesel bus). Labour and overhead for refuelling at \$3.30/fill are a significant cost item, being about 7% of the \$45 or so cost of the fuel per fill. The fast-fill operation was achieved with standard equipment and without staff additions. The refuelling staff were trained in the utilization of the equipment by the fuel supplier, Superior Propane Ltd. and by the training staff of the Equipment Department of OC Transpo.

Certain safety-related equipment developments in use in Europe could be incorporated into propane refuelling practices including:

- . a different mechanism to prevent vehicle fuel tank overfilling beyond the 80% level which eliminates the discharge of propane liquid from the "splitter" or "80% fill" valve (electronically controlled automatic shut-off valves were not available when the buses were equipped with the fuel tank assemblies)
- . a valved empty tank to receive overfill from expansion of cold propane (the overfill tank was reinvestigated during the demonstration)
- . overhead location of the propane refuelling hose, but retaining breakaway coupling
- . mounding or fire insulation of bulk storage tanks of capacities greater than 5000 U.S. gallons, which may be required by large fleets.

Use of propane in a large number of buses at the OC Transpo site would require installation of a larger propane storage facility and multiple dispensers. The economies of scale available in the transportation of propane to the site and reduced distributors' margins provide an opportunity for cost reduction. For example, propane could be delivered to the site by rail tanker. The diesel fuel delivery system already enjoys the benefit of scale.

9. COMPARATIVE COSTS OF PROPANE AND DIESEL BUS OWNERSHIP

9.1 Scope and Methodology

The demonstration provided the cost of operating and maintaining propane and diesel buses under the conditions of the demonstration. This data, together with information from suppliers and potential suppliers of fuel, engines and other components, has been used to develop a series of estimates of the future benefits (or losses) of conversion to propane. The cases considered are:

- i. Bus conversion technology used in the demonstration with current fuel costs.
- ii. Elimination of the winter outdoor parking penalty of the propane bus.
- iii. Conversion of a new bus.
- iv. Conversion of a new bus with 1991 EPA pollution regulations in force (two technologies).
- v. Acquisition of a series-produced (factory-manufactured) propane bus.

The technique used to compare the ownership costs is to determine the Net Present Value (NPV) of the benefits (or loss) of propane bus ownership compared to diesel buses over the remaining useful life of the buses. The NPV technique used eliminates the effect of costs that are common to the two types of buses and corrects the benefits for the time value of money by discounting them over time at an arbitrary discount rate which reflects an implied rate of return on the investments made. A 7% discount rate was used in this analysis. A microcomputer "spread-sheet" approach facilitated calculation of NPV and other

Indicators, such as the maximum conversion cost (or subsidy required) for ownership of propane buses to break even with diesel bus ownership, and the fuel cost differential that is required for propane to compete with diesel fuel.

The variables used in the program include:

- . cost of converting the vehicle (or premium for a factory-produced propane bus)
- . subsidies and tax rebate on vehicles (in 1988 in Ontario there is no sales tax on propane buses, but a 7% sales tax on diesel buses)
- . cost of garage changes and fuel storage and residual values
- . bus life remaining
- . annual kilometrage
- . after-tax cost of propane and diesel fuel
- . fuel economy (litres/100km) of propane and diesel buses
- . discount rate (for NPV).

The buses were assumed to operate over the same routes with the same revenue kilometrage each year (60,000km/yr).

9.2 Results of the Economic Analysis

A summary is given in Exhibit 9.1 and details in Exhibits 9.2a-g.

9.2.1 Demonstration Conditions, Exhibits 9.2a,b

The conversion of buses to propane is not economic using existing technology with propane and diesel fuel priced at the delivered cost to OC Transpo in 1987 of 18.4¢/litre for propane and 39¢/litre for diesel. The high cost of conversion (1984-86 costs) without credit for the diesel engine replaced, the sub-optimum fuel economy achieved (including the winter warm-up penalty) and the high maintenance cost recorded in the demonstration also contributed to the cost differential.

Exhibit 9.1
Summary of Comparative Economics of Propane & Diesel Bus Operations at OC Transpo

<u>EXHIBIT</u>	<u>DESCRIPTION</u>	<u>YEARS</u>	<u>NET PRESENT VALUE</u>	<u>FUEL COST FOR BREAK-EVEN</u> <u>PROPANE</u> <u>DIFFERENTIAL</u> <u>(Diesel Equivalent)</u>
<u>DEMONSTRATIONS</u>				
9.2a	1984 conversion. 1987 costs: propane 18.4¢, diesel 39¢/litre	12	(38570)	10.9 17.05
9.2b	As (a) with credit for diesel engine	12	(28450)	12.85 13.1
9.2c	As (b) without parking penalty	12	(10375)	16.15 9.8
<u>COMMERCIAL OPERATIONS 1991+</u>				
9.2d	New bus converted No pollution control in diesel	18	13790	20.9 5.4
9.2e	New bus converted High cost pollution control in diesel	18	81500	30.0 (4.5)
9.2f	New bus converted Lowest cost pollution control in diesel	18	53160	27.9 (1.5)
9.2g	Factory-equipped propane bus Lowest cost pollution control in diesel	18	60340	29.2 (3.6)

Notes: NPV (.) is equivalent to a required subsidy

1¢/litre differential in the propane cost is equivalent to annual savings of \$320/propane bus

Exhibit 9.2a **Comparative Economic Analysis**

OC TRANSPO PROPANE DEMO BUS CONVERSION: INCREMENTAL COST/SAVINGS
1987 ACTUAL

1	Federal Grant:	\$0.00
2	Provincial lump sum:	\$0.00
3	Provincial sales rebate:	\$0.00
4	Industry Grant:	\$0.00
5	Corporate tax rate:	0.0%
6	Vehicle Type:	CITY BUS
7	Vehicle Life:	12 Years
8	Fuel Type:	NOMO. PUZL
9	Engine Type:	S.I. NOMO PUZL
10	Fuel Consumption:	32100 l/year diesel equiv
11	Location:	OTTAWA ONTARIO
12	Alternative Fuel:	PROPANE
13	Fraction alt fuel:	1.00
14	Maintenance Savings:	(\$0.051) \$/litre alt fuel
15		
16	VEHICLE CONVERSION:	
17	initial investment:	\$30,310.00
18	salvage value:	0.5% initial investment
19	GDP deflator:	5.0% per annum
20	net investment	\$30,225.61
21		
22	FUEL STATION/GARAGE CONVERSION:	
23	initial investment:	\$540.00 per vehicle
24	Station life:	25 years
25	levelled inv cost:	\$46.34 per vehicle/year
26	PV for this vehicle:	\$368.05
27		
28	Discount Rate:	7.0%

CASE DESCRIPTION
Bus retrofit 1984 costs
Operations: Nov 1986 - Oct 1987

VALUES	DIESEL	PROPANE
Fuel Economy (l/100km)	53.5	107.0
Fuel Cost (cents/l)	39.0	18.4
Kilometers/yr	60000	60000
Litres/yr	32100	64680

		Fuel Cost	D E P R E C I A T I O N			
	Year	Differential	Vehicle		Garage	NPV(P)
		\$/litre	rate	\$		\$
30						
31						
32						
33						
34	1	0.0192	0.3%	\$2,515.73	\$21.60	-939.00
35	2	0.0192	0.3%	\$2,515.73	\$21.60	-877.57
36	3	0.0192	0.3%	\$2,515.73	\$21.60	-820.16
37	4	0.0192	0.3%	\$2,515.73	\$21.60	-766.50
38	5	0.0192	0.3%	\$2,515.73	\$21.60	-716.36
39	6	0.0192	0.3%	\$2,515.73	\$21.60	-669.49
40	7	0.0192	0.3%	\$2,515.73	\$21.60	-625.70
41	8	0.0192	0.3%	\$2,515.73	\$21.60	-584.76
42	9	0.0192	0.3%	\$2,515.73	\$21.60	-546.51
43	10	0.0192	0.3%	\$2,515.73	\$21.60	-510.75
44	11	0.0192	0.3%	\$2,515.73	\$21.60	-477.34
45	12	0.0192	0.3%	\$2,515.73	\$21.60	-446.11
46	13	0.0000	0.0%	\$0.00	\$0.00	0.00
47	14	0.0000	0.0%	\$0.00	\$0.00	0.00
48	15	0.0000	0.0%	\$0.00	\$0.00	0.00
49	16	0.0000	0.0%	\$0.00	\$0.00	0.00
50	17	0.0000	0.0%	\$0.00	\$0.00	0.00
51	18	0.0000	0.0%	\$0.00	\$0.00	0.00

53	Total NPV of yearly net benefits	-7900.26
54	plus grants	0.00
55	less Conversion cost - vehicle	-30225.61
	less conversion cost - fuel station	-368.05

BREAK-EVEN VALUES		
Cost Differential	(cents/l dies equiv)	17.05
Propane Price (cents/l)		18.09
Conversion Cost (\$)		-8263.91

TOTAL NPV FINANCIAL -30573.91

Exhibit 9.2b Comparative Economic Analysis

OC TRANSPO PROPANE DEMO BUS CONVERSION: INCREMENTAL COST/SAVINGS
1987 ACTUAL

1 Federal Grant:	\$0.00
2 Provincial lump sum:	\$0.00
3 Provincial sales rebate:	\$0.00
4 Industry Grant:	\$0.00
5 Corporate tax rate:	0.0%
6 Vehicle Type:	CITY BUS
7 Vehicle Life:	12 Years
8 Fuel Type:	HOMO FUEL
9 Engine Type:	S.I. HOMO FUEL
10 Fuel Consumption:	32100 l/year diesel equiv
11 Location:	OTTAWA ONTARIO
12 Alternative Fuel:	PROPANE
13 Fraction alt fuel:	1.00
14 Maintenance Savings:	(\$0.051) \$/litre alt fuel

15	
16 VEHICLE CONVERSION:	
17 initial investment:	\$20,160.00
18 salvage value:	0.5% initial investment
19 GDP deflator:	5.0% per annum
20 net investment	\$20,103.07

21	
22 FUEL STATION/GARAGE CONVERSION:	
23 initial investment:	\$540.00 per vehicle
24 Station life:	25 years
25 levelled inv cost:	\$46.34 per vehicle/year
26 PV for this vehicle:	\$368.05

27	
28 Discount Rate:	7.0%

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CASE DESCRIPTION
Bus retrofit 1984 costs
Operations: Nov 1986 - Oct 1987
Credit for diesel engine \$10150
(7 yrs of 12 yr life)

VALUES	DIESEL	PROPANE
Fuel Economy (l/100km)	53.5	107.8
Fuel Cost (cents/l)	39.0	18.4
Kilometers/yr	60000	60000
Litres/yr	32100	64680

BREAK-EVEN VALUES	
Cost Differential	
(cents/l dies equiv)	13.00
Propane Price (cents/l)	12.06
Conversion Cost (\$)	-8292.17

TOTAL NPV FINANCIAL

Exhibit 9.2c **Comparative Economic Analysis**

OC TRANSPRO PROPANE DEMO BUS CONVERSION: INCREMENTAL COST/SAVINGS
1987 ACTUAL (CORRECTED FOR OUTDOOR PARKING)

1 Federal Grant: \$0.00
2 Provincial lump sum: \$0.00
3 Provincial sales rebate: \$0.00
4 Industry Grant: \$0.00
5 Corporate tax rate: 0.0%
6 Vehicle Type: CITY BUS
7 Vehicle Life: 12 years
8 Fuel Type: MONO FUEL
9 Engine Type: S.I. MONO FUEL
10 Fuel Consumption: 32100 l/year diesel equiv
11 Location: OTTAWA/ONTARIO
12 Alternative Fuel: PROPANE
13 Fraction alt fuel: 1.00
14 Maintenance Savings: (\$0.018) \$/litre alt fuel

15
16 VEHICLE CONVERSION:
17 initial investment: \$20,160.00
18 salvage value: 0.5% initial investment
19 GDP deflator: 5.0% per annum
20 net investment: \$20,103.07
21

22 FUEL STATION/GARAGE CONVERSION:
23 initial investment: \$540.00 per vehicle
24 Station life: 25 years
25 levelled inv cost: \$46.34 per vehicle/year
26 PV for this vehicle: \$360.05
27

28 Discount Rate: 7.0%

Year	Fuel Cost Differential \$/litre	DEPRECIATION		Garage	NPV(P) \$
		Vehicle rate \$			
1	0.0574	0.3%	\$1,673.20	\$21.60	1100.00
2	0.0574	0.3%	\$1,673.20	\$21.60	1110.20
3	0.0574	0.3%	\$1,673.20	\$21.60	1037.65
4	0.0574	0.3%	\$1,673.20	\$21.60	969.76
5	0.0574	0.3%	\$1,673.20	\$21.60	906.32
6	0.0574	0.3%	\$1,673.20	\$21.60	847.03
7	0.0574	0.3%	\$1,673.20	\$21.60	791.61
8	0.0574	0.3%	\$1,673.20	\$21.60	739.03
9	0.0574	0.3%	\$1,673.20	\$21.60	691.43
10	0.0574	0.3%	\$1,673.20	\$21.60	646.19
11	0.0574	0.3%	\$1,673.20	\$21.60	603.92
12	0.0574	0.3%	\$1,673.20	\$21.60	564.41
13	0.000	0.0%	\$0.00	\$0.00	0.00
14	0.000	0.0%	\$0.00	\$0.00	0.00
15	0.000	0.0%	\$0.00	\$0.00	0.00
16	0.000	0.0%	\$0.00	\$0.00	0.00
17	0.000	0.0%	\$0.00	\$0.00	0.00
18	0.000	0.0%	\$0.00	\$0.00	0.00

53 Total NPV of yearly net benefits: 10096.43
54 plus grants: 0.00
55 less Conversion cost - vehicle: -20103.07
less conversion cost - fuel station: -360.05
TOTAL NPV FINANCIAL: -10375.49

CASE DESCRIPTION:
Bus retrofit 1984 costs
Operations: summer 1987
Credit for diesel engine: \$10150

VALUES:	DIESEL	PROPANE
Fuel Economy (l/100km)	53.5	96.7
Fuel Cost (cents/l)	39.0	18.4
Kilometers/yr	60000	60000
Litres/yr	32100	50070

BREAK-EVEN VALUES
Cost Differential (cents/l dies equiv): 9.01
Propane Price (cents/l): 16.15
Conversion Cost (\$): 9784.51

Exhibit 9.2d Comparative Economic Analysis

OC TRANSPO PROPANE FUTURE BUS CONVERSION: INCREMENTAL COST/SAVINGS
1991*

1 Federal Grant:	\$0.00
2 Provincial lump sum:	\$0.00
3 Provincial sales rebate:	\$0.00
4 Industry Grant:	\$0.00
5 Corporate tax rate:	0.0%
6 Vehicle Type:	CITY BUS
7 Vehicle Life:	10 Years
8 Fuel Type:	NOMO FUEL
9 Engine Type:	S.I. NOMO FUEL
10 Fuel Consumption:	31000 l/year diesel equiv
11 Location:	OTTAWA ONTARIO
12 Alternative Fuel:	PROPANE
13 Fraction alt fuel:	1.00
14 Maintenance Savings:	(\$0.018) \$/litre alt fuel
15	
16 VEHICLE CONVERSION:	
17 initial investment:	\$11,200.00
18 salvage value:	0.5% initial investment
19 GDP deflator:	5.0% per annum
20 net investment	\$11,176.73

CASE DESCRIPTION

New bus converted with credits for
diesel equipment recovered
Operations: 1991* WITHOUT pollution control

VALUES	DIESEL	PROPANE
Fuel Economy (l/100km)	53.0	90.0
Fuel Cost (cents/l)	41.0	18.4
Kilometers/yr	60000	60000
Litres/yr	31800	54000

21	
22 FUEL STATION/GARAGE CONVERSION:	
23 initial investment:	\$540.00 per vehicle
24 Station life:	25 years
25 levelled inv cost:	\$46.34 per vehicle/year
26 PV for this vehicle:	\$466.11
27	
28 Discount Rate:	7.0%

		Fuel Cost	DEPRECIATION			
	Year	Differential	Vehicle		Garage	NPV(P)
		\$/litre	rate	\$		\$
30						
31						
32						
33						
34	1	0.0975	5.6%	\$622.72	\$21.60	2362.71
35	2	0.0975	5.6%	\$622.72	\$21.60	2208.14
36	3	0.0975	5.6%	\$622.72	\$21.60	2063.60
37	4	0.0975	5.6%	\$622.72	\$21.60	1928.60
38	5	0.0975	5.6%	\$622.72	\$21.60	1802.50
39	6	0.0975	5.6%	\$622.72	\$21.60	1684.58
40	7	0.0975	5.6%	\$622.72	\$21.60	1574.37
41	8	0.0975	5.6%	\$622.72	\$21.60	1471.30
42	9	0.0975	5.6%	\$622.72	\$21.60	1375.12
43	10	0.0975	5.6%	\$622.72	\$21.60	1285.16
44	11	0.0975	5.6%	\$622.72	\$21.60	1201.00
45	12	0.0975	5.6%	\$622.72	\$21.60	1122.51
46	13	0.0975	5.6%	\$622.72	\$21.60	1049.07
47	14	0.0975	5.6%	\$622.72	\$21.60	980.44
48	15	0.0975	5.6%	\$622.72	\$21.60	916.30
49	16	0.0975	5.6%	\$622.72	\$21.60	856.35
50	17	0.0975	5.6%	\$622.72	\$21.60	800.33
51	18	0.0975	5.6%	\$622.72	\$21.60	747.97

52	
53 Total NPV of yearly net benefits	25430.30
54 plus grants	0.00
55 less Conversion cost - vehicle	-11176.73
less conversion cost - fuel station	-466.11

BREAK-EVEN VALUES

Cost Differential	
(cents/l dies equiv)	5.44
Propane Price (cents/l)	20.94
Conversion Cost (\$)	24987.53

TOTAL NPV FINANCIAL

13787.53

Exhibit 9.2e **Comparative Economic Analysis**

OC TRANSPRO PROPANE FUTURE BUS CONVERSION: INCREMENTAL COST/SAVINGS
1991*

1 Federal Grant:	50.00
2 Provincial lump sum:	50.00
3 Provincial sales rebate:	50.00
4 Industry Grant:	50.00
5 Corporate tax rate:	0.0%
6 Vehicle Type:	CITY BUS
7 Vehicle Life:	18 Years
8 Fuel Type:	MOMO FUEL
9 Engine Type:	S.I. MOMO FUEL
10 Fuel Consumption:	33720 l/year diesel equiv
11 Location:	OTTAWA ONTARIO
12 Alternative Fuel:	PROPANE
13 Fraction alt fuel:	1.00
14 Maintenance Savings:	50.048 \$/litre alt fuel
15	
16 VEHICLE CONVERSION:	
17 initial investment:	\$1,200.00
18 salvage value:	0.5% initial investment
19 GDP deflator:	5.0% per annum
20 net investment	\$1,197.51
21	
22 FUEL STATION/GARAGE CONVERSION:	
23 initial investment:	(\$200.00) per vehicle
24 Station life:	25 years
25 levelled inv cost:	(\$17.16) per vehicle/year
26 PV for this vehicle:	(\$172.64)
27	
28 Discount Rate:	7.0%

		Fuel Cost	DEPRECIATION				
	Year	Differential		Vehicle	Garage	NPV(P)	
		\$/litre		rate	\$		\$
34	1	0.1953	5.6%	\$66.72	(\$0.00)	7667.36	
35	2	0.1953	5.6%	\$66.72	(\$0.00)	7165.76	
36	3	0.1953	5.6%	\$66.72	(\$0.00)	6696.97	
37	4	0.1953	5.6%	\$66.72	(\$0.00)	6258.05	
38	5	0.1953	5.6%	\$66.72	(\$0.00)	5849.39	
39	6	0.1953	5.6%	\$66.72	(\$0.00)	5466.72	
40	7	0.1953	5.6%	\$66.72	(\$0.00)	5109.09	
41	8	0.1953	5.6%	\$66.72	(\$0.00)	4774.85	
42	9	0.1953	5.6%	\$66.72	(\$0.00)	4462.47	
43	10	0.1953	5.6%	\$66.72	(\$0.00)	4170.54	
44	11	0.1953	5.6%	\$66.72	(\$0.00)	3897.70	
45	12	0.1953	5.6%	\$66.72	(\$0.00)	3642.71	
46	13	0.1953	5.6%	\$66.72	(\$0.00)	3404.40	
47	14	0.1953	5.6%	\$66.72	(\$0.00)	3181.68	
48	15	0.1953	5.6%	\$66.72	(\$0.00)	2973.53	
49	16	0.1953	5.6%	\$66.72	(\$0.00)	2779.00	
50	17	0.1953	5.6%	\$66.72	(\$0.00)	2597.20	
51	18	0.1953	5.6%	\$66.72	(\$0.00)	2427.29	

53 Total NPV of yearly net benefits	82525.51
54 plus grants	0.00
55 less Conversion cost - vehicle	-1197.51
less conversion cost - fuel station	172.64

TOTAL NPV FINANCIAL

81500.64

CASE DESCRIPTION

New bus converted with credits for
diesel equipment recovered
Operations: 1991* WITH pollution control

VALUES	DIESEL	PROPANE
Fuel Economy (l/100km)	56.2	93.0
Fuel Cost (cents/l)	48.0	18.4
Kilometers/yr	64160	60000
Litres/yr	36058	55800
Vehicle conversion (\$)	12000	13200

NOTES

1. 6% increase in diesel fuel consumption
2. High cetane, low sulphur diesel fuel at 7 cents/l premium
3. 16 km/day added for return to garage for regeneration (4160km/yr)
4. Labour for regeneration 8 min/day (\$3.50/day)
5. Filter replacements \$133/yr
6. On-bus pollution control equipment maintenance at \$167/yr

BREAK-EVEN VALUES

Cost Differential	
(cents/l dies equiv)	-4.50
Propane Price (cents/l)	29.90
Conversion Cost (\$)	82700.64

Exhibit 9.2f **Comparative Economic Analysis**

OC TRANSPRO PROPANE FUTURE BUS CONVERSION: INCREMENTAL COST/SAVINGS
1991*

1 Federal Grant:	\$0.00
2 Provincial lump sum:	\$0.00
3 Provincial star rebate:	\$0.00
4 Industry Grant:	\$0.00
5 Corporate tax rate:	0.0%
6 Vehicle Type:	CITY BUS
7 Vehicle Life:	10 Years
8 Fuel Type:	HOMO FUEL
9 Engine Type:	S.I. HOMO FUEL
10 Fuel Consumption:	33120 l/year diesel equiv
11 Location:	OTTAWA ONTARIO
12 Alternative Fuel:	PROPANE
13 Fraction alt fuel:	1.00
14 Maintenance Savings:	\$0.037 \$/litre alt fuel
15	
16 VEHICLE CONVERSION:	
17 initial investment:	\$7,200.00
18 salvage value:	0.5% initial investment
19 GDP deflator:	5.0% per annum
20 net investment	\$7,185.04
21	
22 FUEL STATION/GARAGE CONVERSION:	
23 initial investment:	\$340.00 per vehicle
24 Station life:	25 years
25 levelled inv cost:	\$29.18 per vehicle/year
26 PV for this vehicle:	\$293.48
27	
28 Discount Rate:	7.0%

29						
30		Fuel Cost	D E P R E C I A T I O N			
31	Year	Differential	Vehicle	Garage	NPV(F)	
32		\$/litre	rate	\$	\$	
33						
34	1	0.1450	5.6%	\$400.32	\$13.60	5633.50
35	2	0.1450	5.6%	\$400.32	\$13.60	5264.95
36	3	0.1450	5.6%	\$400.32	\$13.60	4920.51
37	4	0.1450	5.6%	\$400.32	\$13.60	4590.61
38	5	0.1450	5.6%	\$400.32	\$13.60	4297.77
39	6	0.1450	5.6%	\$400.32	\$13.60	4016.60
40	7	0.1450	5.6%	\$400.32	\$13.60	3753.84
41	8	0.1450	5.6%	\$400.32	\$13.60	3508.26
42	9	0.1450	5.6%	\$400.32	\$13.60	3278.75
43	10	0.1450	5.6%	\$400.32	\$13.60	3064.25
44	11	0.1450	5.6%	\$400.32	\$13.60	2863.78
45	12	0.1450	5.6%	\$400.32	\$13.60	2676.43
46	13	0.1450	5.6%	\$400.32	\$13.60	2501.34
47	14	0.1450	5.6%	\$400.32	\$13.60	2337.70
48	15	0.1450	5.6%	\$400.32	\$13.60	2184.77
49	16	0.1450	5.6%	\$400.32	\$13.60	2041.94
50	17	0.1450	5.6%	\$400.32	\$13.60	1908.26
51	18	0.1450	5.6%	\$400.32	\$13.60	1783.42
52						

53 Total NPV of yearly net benefits	64634.57
54 plus grants	0.00
55 less Conversion cost - vehicle	-7185.04
less conversion cost - fuel station	-293.48

TOTAL NPV FINANCIAL 53156.05

CASE DESCRIPTION

New bus converted with credits for diesel equipment recovered
Operations: 1991*, low cost pollution control

VALUES	DIESEL	PROPANE
Fuel Economy (l/100km)	55.2	93.0
Fuel Cost (cents/l)	45.5	18.4
Kilometers/yr	60000	60000
Litres/yr	33120	55800
Vehicle conversion (\$)	6000	13200

NOTES

1. 4% increase in diesel fuel consumption
2. High cetane, low sulphur diesel fuel at 4.5 cents/l premium
3. On-line regeneration, no increase in km
4. No labour for regeneration
5. Filter replacements \$83/yr
6. On-bus pollution control equipment maintenance at \$84/yr

BREAK-EVEN VALUES

Cost Differential	
(cents/l dies equiv)	-1.46
Propane Price (cents/l)	27.07
Conversion Cost (\$)	60356.05

Exhibit 9.2g Comparative Economic Analysis

OC TRANSPRO PROPANE FUTURE BUS CONVERSION: INCREMENTAL COST/SAVINGS
1991*

1 Federal Grant:	50.00
2 Provincial lump sum:	50.00
3 Provincial star rebate:	50.00
4 Industry Grant:	50.00
5 Corporate tax rate:	0.0%
6 Vehicle Type:	CITY BUS
7 Vehicle Life:	10 Years
8 Fuel Type:	MOMO FUEL
9 Engine Type:	S.I. MOMO FUEL
10 Fuel Consumption:	33120 l/year diesel equiv
11 Location:	OTTAWA ONTARIO
12 Alternative Fuel:	PROPANE
13 Fraction alt fuel:	1.00
14 Maintenance Savings:	\$0.037 \$/litre alt fuel
15	
16 VEHICLE CONVERSION:	
17 initial investment:	50.00
18 salvage value:	0.5% initial investment
19 GDP deflator :	5.0% per annum
20 net investment	50.00
21	
22 FUEL STATION/GARAGE CONVERSION:	
23 initial investment:	\$340.00 per vehicle
24 Station life:	25 years
25 levelled inv cost:	\$29.18 per vehicle/year
26 PV for this vehicle:	\$293.48
27	
28 Discount Rate:	7.0%
29	

	Year	Fuel Cost Differential \$/litre	DEPRECIATION		NPV(P) \$
			Vehicle rate %	Garage \$	
34	1	0.1450	5.6%	\$0.00	\$13.60
35	2	0.1450	5.6%	\$0.00	\$13.60
36	3	0.1450	5.6%	\$0.00	\$13.60
37	4	0.1450	5.6%	\$0.00	\$13.60
38	5	0.1450	5.6%	\$0.00	\$13.60
39	6	0.1450	5.6%	\$0.00	\$13.60
40	7	0.1450	5.6%	\$0.00	\$13.60
41	8	0.1450	5.6%	\$0.00	\$13.60
42	9	0.1450	5.6%	\$0.00	\$13.60
43	10	0.1450	5.6%	\$0.00	\$13.60
44	11	0.1450	5.6%	\$0.00	\$13.60
45	12	0.1450	5.6%	\$0.00	\$13.60
46	13	0.1450	5.6%	\$0.00	\$13.60
47	14	0.1450	5.6%	\$0.00	\$13.60
48	15	0.1450	5.6%	\$0.00	\$13.60
49	16	0.1450	5.6%	\$0.00	\$13.60
50	17	0.1450	5.6%	\$0.00	\$13.60
51	18	0.1450	5.6%	\$0.00	\$13.60
52					

53 Total NPV of yearly net benefits	60634.57
54 plus grants	0.00
55 less Conversion cost - vehicle	0.00
less conversion cost - fuel station	-293.48

TOTAL NPV FINANCIAL

60341.09

CASE DESCRIPTION

New bus compared to low cost pollution
controlled diesel

VALUES	DIESEL	PROPANE
Fuel Economy (l/100km)	55.2	93.0
Fuel Cost (cents/l)	45.5	18.4
Kilometers/yr	60000.0	60000.0
Litres/yr	33120	55800
Vehicle conversion (\$)	6000	13200.0

NOTES

1. 4% increase in diesel fuel consumption
2. High cetane, low sulphur diesel fuel at 4.5 cents/l premium
3. On-line regeneration, no increase in km
4. No labour for regeneration
5. Filter replacements \$83/yr
6. On-bus pollution control equipment maintenance at \$84/yr

BREAK-EVEN VALUES

Cost Differential	
(cents/l dies equiv)	-3.61
Propane Price (cents/l)	29.15
Conversion Cost (\$)	60341.09

The key indicators show that if conditions of the demonstration are not changed:

- a subsidy of \$38,500/propane bus would be required to bring ownership costs in propane and diesel buses to the same level over 12 years of operation during the remaining life of the converted "old" bus
- break-even is possible at a propane price of 10.9¢/litre, or if the price of diesel fuel were increased by 17.05¢/litre to the 56¢/litre range (a price anticipated before 1990 in the original planning period)
- the requirement for a subsidy or increase in the differential between diesel and propane would be reduced if credit were given for the remaining life of the diesel engine displaced. The value assigned by OC Transpo to the 5-year old displaced diesel engine was \$10,150, based on an average 12-year engine life expectancy, and straight-line depreciation over the 5 years of use. Given the \$10,150 credit, the price of propane needed to achieve break-even would be 12.85¢/litre (a 5.55¢/litre reduction over the 1987 price). Alternatively, the price of diesel fuel would need to increase to about 52¢/litre.

9.2.2 Actual Costs of Diesel and Propane Bus Ownership

The costs measured in the demonstration were only those expected to differ between propane and diesel use. While it is valid to use only these measured costs in the differential economic analysis, it should be noted that both types of buses incur common costs for maintenance of the interior and exterior of the bus (excluding engines and fuel storage-related items), garaging, plant maintenance and administration. Exhibit 9.3 provides a perspective on the common cost elements.

Exhibit 9.3
Cost Comparison of Diesel and Propane Demonstration Fleets
(Cost/100 km)

	<u>Propane</u>		<u>Diesel</u>
	<u>1986</u>	<u>1987</u>	<u>1987</u>
<u>MEASURED COSTS FUEL AND ENGINE SYSTEM</u>			
Fuel	20.37	20.16	20.94
Other Related Operations	3.64	4.16	3.28
Maintenance	<u>17.22</u>	<u>15.43</u>	<u>8.36</u>
SUBTOTAL MEASURED COSTS	41.23	39.75	32.58
<u>OTHER ESTIMATED FROM OC TRANSPO BUDGET</u>			
Other Transportation Operations	100.88	100.88	100.88
Other Maintenance	30.15	30.15	30.15
Plant Maintenance	14.07	14.07	14.07
Administration & General	<u>23.32</u>	<u>23.32</u>	<u>23.32</u>
SUBTOTAL OTHER OPERATING COST	168.42	168.42	168.42
<u>TOTAL OPERATING COST \$/100 KM</u>	<u>209.65</u>	<u>208.17</u>	<u>201.00</u>

The costs measured in the demonstration represent only about 19% of the total estimated cost of propane bus ownership in 1987. The importance of the measured cost elements is that they represent costs which can be changed by the alternative fuel technology. Most of the common cost elements have little, if any, potential for improvement.

The cost of fuel is the most important of the items considered in relating the operating cost of propane buses to diesel. As shown in Exhibit 9.4 fuel savings in the range of \$460-696/bus/year were achieved by propane substitution, but the magnitude of the saving was less than originally estimated. The reasons for this are:

Exhibit 9.4

Comparative Fuel Cost Data

	FUEL COSTS (1) cents/litre		PROPANE COSTS AS % DIESEL			FUEL ECONOMY		
	Propane	Diesel	By Volume	By Energy Content	Actual in Demo. (3)	litres/100km Propane Diesel	Propane as % Diesel	
AVERAGE								
1987 (12 mo.)	18.40	39.20	46.9	70.4	96.3	109.6	53.4	2.05
1986 (12 mo.)	19.05	40.66	46.9	70.3	94.7	100.1	53.5 (4)	2.02
1985 (4 mo.)	19.96	42.83	46.6	69.9	95.4	109.6	53.5 (4)	2.05
SELECTED MONTHS								
1984								
Apr.	23.53	37.9	62.1	93.1	N/A	N/A	N/A	N/A
June	17.85	39.13	45.6	68.4	N/A	N/A	N/A	N/A
Dec.	18.95	41.37	45.8	68.7	78.0	91.4	53.65 (5)	1.70
1985								
June	18.95	40.67	46.6	69.9	65.9	75.7	53.5	1.41
Oct.	18.95	43.28	43.8	65.7	83.4	101.9	53.5	1.90
Nov.	19.60	43.40	45.2	67.7	96.1	113.8	53.5	2.13
Dec.	22.33	43.98	50.8	76.2	123.3	129.9	53.5	2.43
1986								
Jan.	22.33	44.40	50.3	75.4	130.4	138.7	53.5	2.59
Feb.	22.30	44.20	50.5	75.7	120.9	128.2	53.5	2.40
June	18.40	42.10	43.7	65.6	74.3	91.0	53.5	1.70
Dec.	18.40	39.00	47.2	70.8	97.6	110.7	53.5	2.07
1987								
Jan.	18.40	39.00	47.2	70.8	116.3	127.2	51.6	2.47
Jul.	18.40	39.00	47.2	70.8	82.9	90.8	51.7	1.76
Aug.	18.40	39.50	46.6	69.9	94.8	102.0	50.1	2.04
Dec.	18.40	39.50	46.6	69.9	134.1	155.2	53.9	2.88

NOTES:

(1) Ontario fuel sales tax on diesel included: 1985, 1987 9.3 cents/litre;
1986 9.9 cents/litre, propane not taxed.

(2) At 60,000km/yr/bus, annual fuel cost savings from use of propane:

1987: 460 \$

1986: 696 \$

1985: 628 \$

(3) Propane cost/100km as % diesel cost/100km. Volume based on fuel added to bus.

(4) Estimated

(5) Track test ADD cycle

- I. High fuel consumption of buses in the demonstration compared to the target level (1.8 volumes of propane substituting for 1 volume of diesel) and to the level (1.7:1) achieved in the track test. For example, in 1987 the ratio was 2.05:1.
- II. Excessive propane consumption of buses in winter.
- III. Inherent high efficiency of the high compression diesel engine compared to that of the spark-ignition engine and the high energy content of a given volume of diesel fuel relative to the same volume of propane.

The wide variation in the cost of fuel consumed shows the combined effect of changes in the relative price/litre of propane and diesel during 1985 and 1986 and the even higher impact of seasonal variations in the efficiency of the propane buses. Thus, while the price of a litre of propane ranged from 44% to 62% of the price of a litre of diesel fuel, the cost/100km relationship varied from a low of 66% to a high of 134% over the demonstration period.

In 1987 the price of diesel fuel and propane delivered to OC Transpo averaged at 39.2¢/litre and 18.4¢/litre respectively. This provided a 3.7% fuel cost advantage for the propane buses over the diesel buses - equivalent to an annual saving of \$425. If the fuel economy ratio of the ADB track test had been achieved in 1987 operations, the saving over 60,000km of service would have been about \$2,500.

9.2.3 Reduction of the Winter Fuel Penalty, Exhibit 9.2c

If means had been available to eliminate the practice of warming up the propane buses in the "winter months" by running them while parked outdoors, a substantial improvement in fuel economy would have been possible. Exhibit 9.2c illustrates the effect of this improvement,

which could amount at 1987 diesel and propane prices to a fuel cost saving in the region of \$1200-1300/year. Maintenance costs could also be reduced if winter parking problems were eliminated. The combined effect would be:

- . a reduced subsidy requirement (NPV of subsidy, reduced to \$28,000)
- . the propane price required for break-even would be about 16¢/litre (6¢/litre more than the break-even price with winter parking problems).

9.2.4 Estimates of Future Costs

Conversion Without New Pollution Control Requirements, Exhibit 9.2d

The demonstration points to the need to adopt the latest proven carburetion technology in future bus conversions. Improved fuel economy and somewhat lower maintenance costs would be a minimum target for such future conversions. The fuel economy of the diesel engines will also be improved in the future to partly offset gains made through advances in propane technology. This would assume that the conversions are made before planned strict pollution legislation forces the adoption by diesel manufacturers of technologies which exact a fuel economy penalty and high pollution control costs in the operation of diesel buses.

The cost of diesel fuel is expected to increase relative to propane due to increased demand for diesel, improved cost recovery in refining and modest crude oil price increases from present depressed levels. By 1991 the world and Canada's supply of propane will be substantially in excess of conventional market requirements. The price of propane is therefore expected to be depressed relative to diesel fuel. A price of 41¢/litre for diesel fuel and continuation of the present 18.4¢/litre for propane is therefore assumed in the 1990-91 scenario.

New buses are assumed to have the 18-year life targeted by MTO and full credit can be taken for the displaced new diesel engine. In this case involving factory conversion of new buses, full credit can be taken for the displaced diesel engine and conversion to propane can be cost-effective. Alternatively, a somewhat higher conversion net cost than assumed may be tolerable. Break-even is achieved even at 1987 fuel costs; break-even would be possible even if the price of propane were to increase to about 21¢/litre.

Conversion With New Pollution Control Requirements, Exhibit 9.2e

This scenario is considered the most likely for 1991-95 when new buses will conform to the 1991 EPA pollution control legislation, diesel fuel for use in pollution-controlled buses conforms to standards now proposed by EPA, and costs to levels estimated by major refiners in the U.S. and Canada. In this scenario the cost of low sulphur, high cetane diesel fuel is estimated at 48¢/litre when propane is at 18.4¢/litre; fuel economy penalties are severe for diesel engines equipped with particulate traps, but less for propane engines equipped with 3-way catalyst systems. In addition, as indicated by engine manufacturers, the initial cost and maintenance cost of pollution-controlled buses will be higher than for current buses.

Under these circumstances the analysis shows that conversion to propane could be very cost-effective with savings in the \$80,000 range achieved over 18 years. The high maintenance costs of the diesel buses, reduced fuel economy and the investment required in pollution control equipment indicate that the propane route could be profitable, even if it were priced higher than diesel fuel on an energy basis.

Conversion With Low Cost Pollution Control, Exhibit 9.2f

An alternative technology for particulate control in the diesel engine is in the research phase. This technology is being developed for

trucks and, if successful and applicable to buses, could provide a lower cost system with continuous or semi-continuous regeneration of the particulate filter without a requirement for a filter burn-off period at the garage (a perceived requirement for the monolithic filter type of particulate trap) and with a reduced fuel economy penalty.

A comparison of propane and diesel bus costs in this environment shows that propane is still an attractive alternative, since over \$50,000 in savings could be available over the life of the bus from conversion.

New Bus Manufacture, Exhibit 9.2g

The benefits of new technology would be maximized if series-manufactured dedicated propane buses were available. Manufacturers of propane and diesel engines have indicated that their replacement of the diesel fuel injection system (which frequently accounts for 25% of the total cost of a diesel engine) by the lower-cost spark-ignition system could result in cost savings sufficient to overcome the increased cost of \$2200 or so of the on-vehicle propane fuel storage tank assembly. Furthermore, the 3-way catalyst pollution control system required for the propane engine is likely to be lower in cost than the system for diesel engine exhaust control which must deal with particulates. These factors, together with the economies of series production available to a future propane engine manufacturer, could lead to the situation where no premium in cost is incurred in the purchase of a propane bus.

Given the anticipated costs of diesel fuel and propane, a substantial benefit could be achieved by the use of propane: a benefit would still be available if propane were the same price as diesel on an energy basis.

9.3 Discussion of the Benefits of Propane Use

The analysis of experienced costs and future scenarios indicates that the 1983-84 propane technology is not likely to provide cost-effective conversions, even if the major operational problem of bus parking outdoors were solved. Rework of the current propane engine design, and particularly the use of new propane carburetion technology, could provide a cost-saving opportunity if the buses converted could be operated over an extended life of 16-18 years. New or recently acquired buses would be suitable candidates, if credit were given for the diesel engine displaced.

However, the benefits from an updated propane technology are most attractive when propane buses are acquired as a means to achieving a radically new low level of vehicle exhaust emissions. Current work by diesel engine manufacturers clearly shows that the future cost of acquisition, operation and maintenance of diesel buses that conform to the 1991 standards will be substantially higher than today. A number of these manufacturers are supplying, testing or developing engines which will operate on alternative fuels such as methanol, natural gas or propane. The scenarios examined for operation of propane buses in this pollution-sensitive environment show that adoption of the alternative fuel approach may be the most cost-effective way to meet the standards set for 1992 and beyond.

The high cost differential estimated between the propane and diesel bus scenarios in the low pollution environment indicates that even if the price of high quality diesel fuel and the cost of pollution control equipment are somewhat less than anticipated, propane could be a cost-effective option.

The major problem concerning the adoption of alternative fuels is the complexity and cost of diversifying bus operations and maintenance. However, diversification is already underway. The 2-stroke diesel

engine is being challenged in the bus transit market by the 4-stroke engine with its potential for lower fuel consumption; articulated buses are now being incorporated into fleets that were hitherto dominated by the industry standard - the GM 40 ft. transit bus; new ownership and the establishment of European-owned bus manufacture in N. America are bringing other product changes to the market and bus properties.

The requirement for enhanced pollution control will increase the flux of product changes and introduce new cost problems in staff training, changes in maintenance practices and equipment and in the diversification of component inventories. This emerging period of change and emphasis on pollution control could provide a new opportunity for alternative fuels in transit operations. The relative cost advantage of new propane bus designs compared to diesel bus designs in the upcoming pollution control era may overcome the problems associated with further diversification of transit bus equipment.

10. INFORMATION TRANSFER AND PUBLICITY

10.1 Publicity and Public Enquiries

The demonstration was officially opened at a ceremony held in Ottawa on 21 November 1984 by representatives of the Regional Municipality of Ottawa-Carleton, the Ministry of Energy Ontario, the Ministry of Transportation Ontario, Energy, Mines and Resources Canada, OC Transpo and the Canadian Urban Transit Association. The opening ceremony, press conference and demonstration of the first propane bus converted under the program were reported by the press. No further project publicity events were scheduled, the objective being to await completion of the data collection process before initiation of further publicity events. The public relations department at OC Transpo and the project manager responded to requests for information received from the public and the media (interviews carried on national and local television and for technical publications and local newspapers).

The propane buses carried signs inside indicating that they were involved in a propane demonstration under the joint financial sponsorship of the Ontario and Federal governments.

10.2 Publications and Technical Information Transfer

Interim reports on the technical and operational aspects of the propane bus demonstration were given to transit operators at meetings sponsored by the Ontario Urban Transit Association (OUTA) and by the Canadian Urban Transit Association (CUTA), the Roads and Transportation Association of Canada (RTAC) and the American Public Transit Association (APTA). The presentations included summaries of the performance to date of the propane fleet, comparative economics of propane and diesel buses, details of engine tests (conducted at the Ontario Research Foundation), project management and the data collection and analysis system. These items were also included in a 1986 paper published in Transportation

Forum.

One of the APTA meetings in Ottawa on 13 May 1987 provided an opportunity to transit property managers to inspect and ride the propane buses and to inspect the propane storage and bus test facilities at OC Transpo.

Papers were presented at three international meetings concerned with alternative fuels: a feature of these being the opportunity for the managers of the demonstrations of propane buses at OC Transpo and of natural gas buses at Hamilton Street Railway to present joint papers and to discuss and compare the characteristics of gaseous-fuelled buses with those operated on methanol.

The list of publications is given in Appendix 7.

10.3 European Information Exchange

Before selection of the propane engine supplier, and during the demonstration, visits were made by the Project Manager, the consultant and some members of the Steering Committee to European manufacturers of propane engines (Daimler-Benz, and M.A.N. in West Germany, Dereco/Iveco/Fiat in Italy and Switzerland), to suppliers and developers of propane carburetion equipment (TNO Road Research Laboratory, Vialle, Landi den Hartog and Necam in The Netherlands), propane dispensers (Schweim, W. Germany), a propane distributor (BK Gas in The Netherlands), a manufacturer of propane buses (Daf-Gräf & Stift, Austria) and two properties operating propane buses (Amsterdam Stransit and Vienna Transit).

Valuable engineering information on current and future propane engines and controls and on safety and operating procedures was obtained.

Information was exchanged with Vienna Transit on current propane bus operations, safety and developments in pollution control. Vienna Transit began propane operations in 1975 with dual-fuel diesel-LPG buses and subsequently switched to mono-fuel LPG spark-ignition engines manufactured by M.A.N. from the company's 4-stroke diesel engines. Vienna Transit now has 550 propane-fuelled transit buses in service, including single-deck, double-deck and articulated models. The average LPG consumption of the single-deck buses is 89 litres/100km, of the double-deck buses, 113 litres/100km. The articulated buses have dual-fuel systems.

The fuel economy data cannot be compared directly with that at OC Transpo, because of the different size and duty of the buses at the two locations and the difference in fuel composition: Vienna uses a propane/butane mix with a higher energy content than the HD-5 propane used in Ottawa.

The propane consumption in Vienna buses includes only a small penalty for warm-up of the buses in winter. The buses are parked overnight in roofed-over, but otherwise open, structures. The warm-up fuel consumption is minimized by the use of a timed water heater on each bus, which is fuelled by propane from a small auxiliary storage tank.

Vienna Transit is now testing a 3-way catalyst pollution control system in revenue service. The pollution control technology and equipment was developed by the TNO Road Research Laboratory, whose tests indicate that the 1991 EPA level of pollution control can be met.

The 550 propane buses based in 4 garages in the Vienna Transit system consume 60,000 litres of LPG per day. The LPG is supplied from the local oil refinery at a special incentive price which is currently one third of the price of diesel fuel on a volumetric basis.

The safety record of propane at Vienna Transit was stated to be

excellent: only minor incidents have been reported in over 12 years of propane bus operation.

10.4 Safety

Information on propane safety was exchanged with propane supply companies, major users, fire and fuel safety organizations in Canada, the U.S. and Europe. A manual on safety at propane storage and dispensing facilities and in buses was prepared for OC Transpo with financial support from Transport Canada (Appendix 6).

10.5 Data Available from the Demonstration

Appendix 7 lists the reports and publications available from the demonstration including:

- . technical papers presented at public meetings
- . quarterly and other progress reports issued during the demonstration
- . technical notes issued to the Steering Committee on such items as special tests, engine failures, diesel and propane costs, visits, technical service, safety
- . minutes of the Steering Committee meetings.

11. CONCLUSIONS AND RECOMMENDATIONS

11.1 Conclusions on the Objectives

- i. The objectives of the demonstration were achieved.
- ii. The demonstration provides sufficient information for OC Transpo management to reach a conclusion on the costs and benefits of the use of the current series of propane buses.

11.2 Conclusions on Operation of the Propane Fleet at OC Transpo

- i. The demonstration clearly shows that OC Transpo can routinely and safely provide transit service with a propane bus fleet with its present staff and the St. Laurent maintenance facilities.
- ii. The demonstration shows that additional staff training is required to provide the same level of experience and capability for propane bus operations now available in OC Transpo diesel fleet operations.

11.3 Conclusions on Economics with Current Technology Buses

- i. The propane buses now in service have total operating costs (direct operating and maintenance costs) only slightly higher than those for diesel buses of the same age and type. Fuel cost savings available from the use of propane are outweighed by increased maintenance costs associated with the current prototype engines.
- ii. Conversion of more buses to propane will not be cost-effective in the short term if the propane engine conversion technology used in the demonstration continues to be used.

11.4 Conclusions on Future Bus Designs

- i. The competitiveness of the propane bus will be improved if design features are included in its manufacture, which will increase component durability and reduce the frequency and cost of maintenance. Many of these required features have been defined in the present demonstration and many have been demonstrated in buses recently delivered to Vienna Transit.

11.5 Conclusions on Safety

- i. The operation of the propane buses and the fuelling facility was without major incident.
- ii. The outdoor parking of propane buses in winter is a major impediment to the economic use of propane in the present OC Transpo environment. With current technology safe indoor storage of propane buses at OC Transpo cannot be guaranteed at an economic level.

11.6 Recommendations

- i. Propane may be considered as a fuel for transit buses by properties where outdoor parking and bus operation are not affected by extremely cold weather.
- ii. The improvements defined in the present demonstration should be verified in a further propane bus demonstration.
- iii. Future demonstrations of propane buses should utilize a management structure and data-gathering and analysis process similar to those developed during this demonstration.